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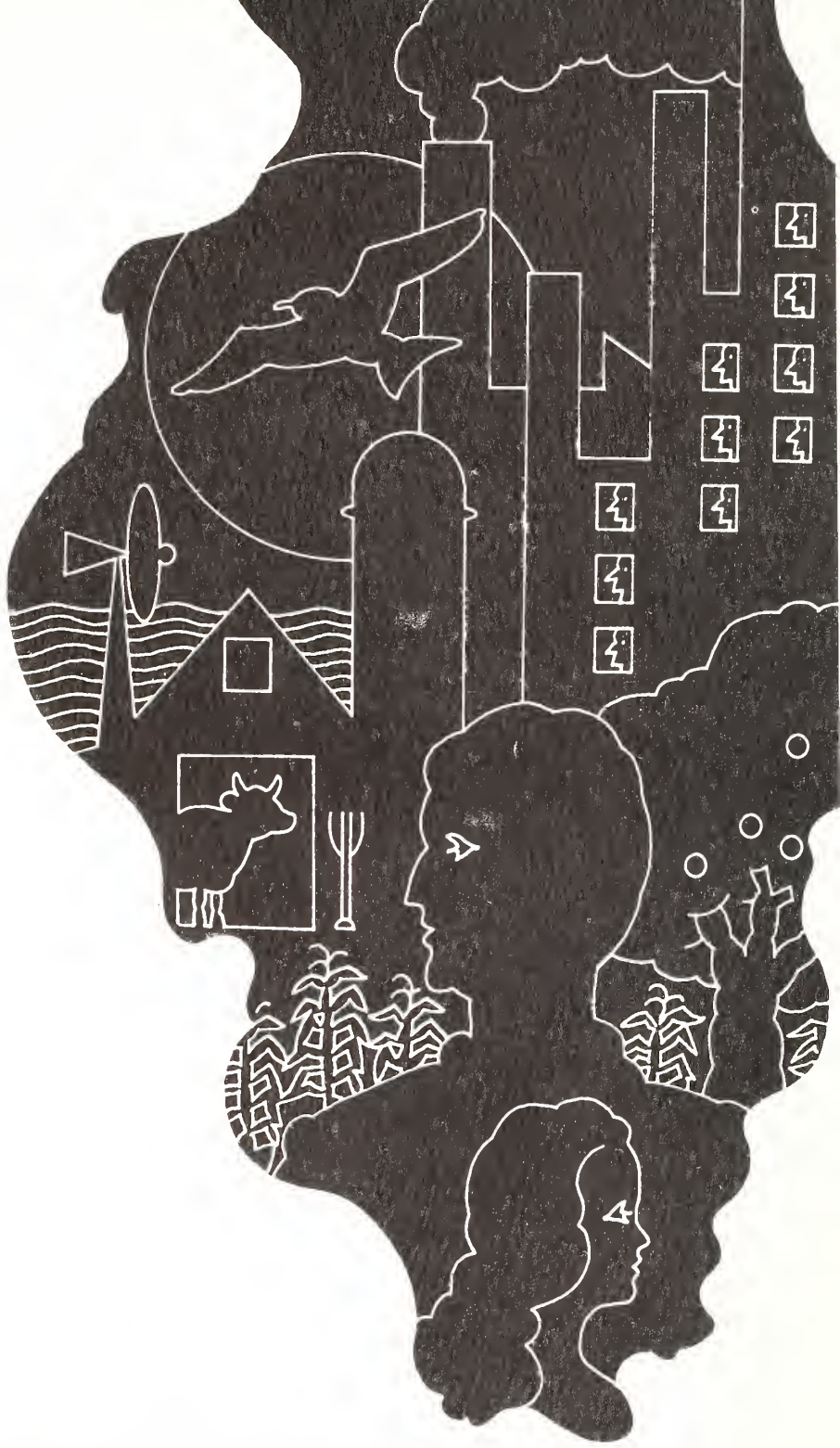

# SOME PROPERTIES OF COAL SPOILBANK AND REFUSE MATERIALS RESULTING FROM SURFACE–MINING COAL IN ILLINOIS

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# SOME PROPERTIES OF COAL SPOILBANK AND REFUSE MATERIALS RESULTING FROM SURFACE-MINING COAL IN ILLINOIS

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# INTRODUCTION

The Cooperative Wildlife Research Laboratory, Southern Illinois University at Carbondale, during 1970 and 1971 surveyed pre-law (prior to 1 January 1962) and post-law lands (103,181 and 60,462 acres, respectively) in Illinois surface mined for coal as of 30 June 1971 (Haynes and Klimstra 1975). This survey updated existing knowledge of the acreage, ownership, condition, and utilization of these lands. During the survey, 2,084 samples of spoilbank material and 22 samples of refuse material (slurry and gob) were collected from affected areas (Appendix, Tables A and B) for later determination and analysis of selected chemical and physical properties. Because of the need to reclaim some pre-law and other problem spoil and refuse areas (Haynes and Klimstra 1975), this publication is intended to provide results of these analyses and to establish parameters useful in planning for the reclamation and/or the use of lands subjected to coal surface mining (Fig. 1). The following are the specific objectives:

1) To determine and evaluate the relationships between selected chemical and physical parameters of spoilbank material and

   a) Coal seams mined
   b) Vegetation density less than 25 percent; and greater than 25 percent
   c) Age of the spoil material

2) To identify and describe the relationships between pH of spoilbank material and other selected chemical parameters

3) To provide a detailed description of the chemical properties of slurry and gob refuse based on the relatively few samples that were analyzed

4) To interpret and discuss the results from the objectives listed above with regard to the amount, location, and distribution of previously delineated problem areas (Haynes and Klimstra 1975; Klimstra and Terpening 1974)

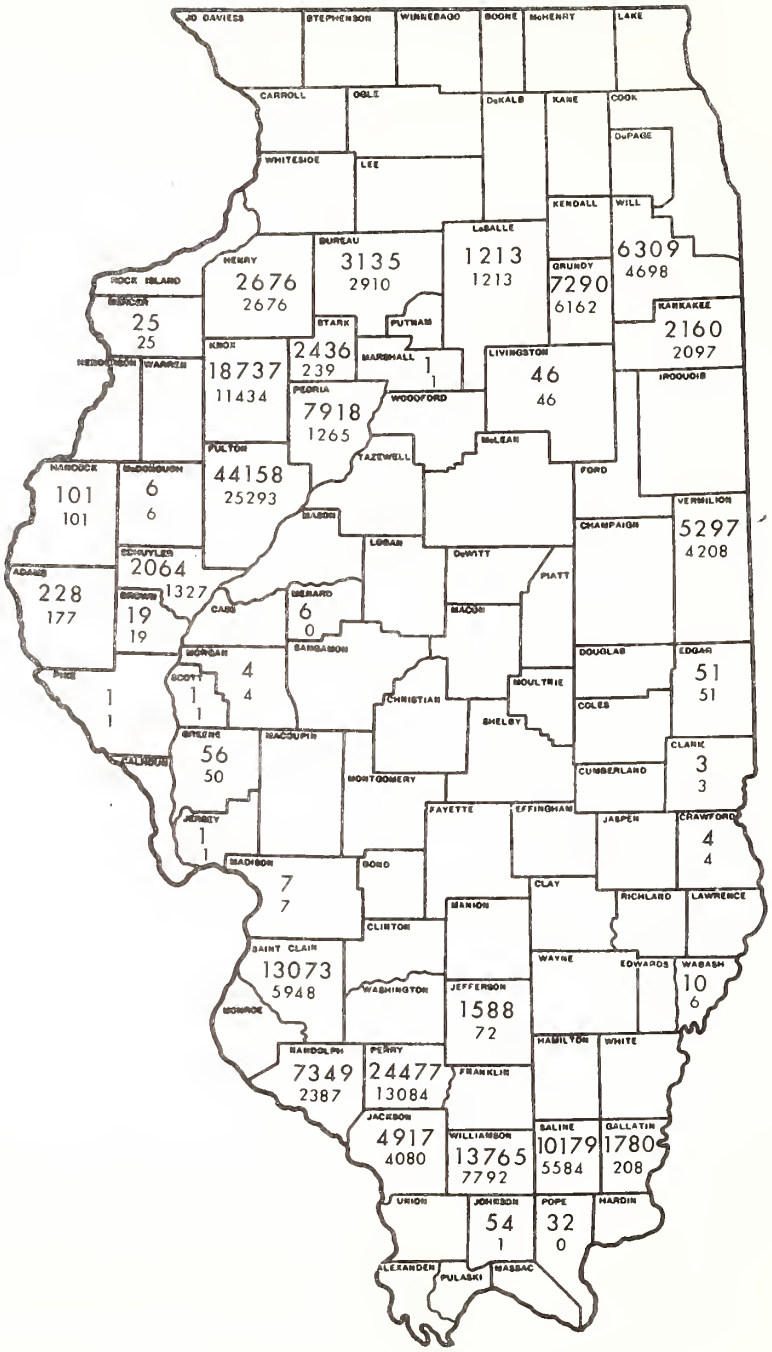


Fig. 1. Acreage surface mined for coal in counties of Illinois as of 30 June 1974. Larger numerals depict total county acreage (Illinois Department of Mines and Minerals 1975a); smaller numerals represent pre-law acreage (Haynes and Klimstra 1975).

5) To provide suggestions and incentives for further research.

This publication contributes an overall evaluation of previously reported research and a summary of current reclamation techniques. Both county and regional situations of interest in developing a purposeful understanding of the nature and characteristics of coal surface mining in Illinois are evaluated.

# REVIEW OF LITERATURE

The initial physical and chemical properties affecting the establishment and growth of vegetation on spoil material are a result of the composition and thickness of the overburden and the method of mining (Limstrom 1960; Limstrom and Deitschman 1951). The material that overlies the coal seams lacks uniformity in physical and chemical properties as well as in the proportion and arrangement of the various strata (Limstrom 1960; Grandt and Lang 1958; Limstrom and Deitschman 1951; Thurn 1953; and Croxton 1928). Hence, extreme variability of site factors has often been encountered, even within the same coal field. However, one or more site factors may not vary depending on the placement, composition, and thickness of the overburden (Limstrom 1960). The evolution of newly created spoilbank material is controlled by at least five major factors: (1) the mixing and placement of the overburden material, (2) weathering, (3) vegetation and other organisms that live in or on the spoil, (4) land relief and its effect on moisture condition, (5) time, and (6) human activity (Thorp 1968).

## Physical Properties

The physical properties usually reported are the relative proportion of rock and soil-size particles (less than 2 mm in diam), texture, and aggregation. These are important because of their effects on aeration, moisture, and nutrient availability. The effect of any one site factor is difficult to evaluate, since there are interactions with many other factors. However, one or two site factors may be more dominant or influential than the others (Limstrom 1960).

The percentage of soil-size particles necessary for successful establishment and growth of plants is variable, but less than 20 percent has been considered a probable limiting factor (Clark 1954; Bramble 1952). It has been generally concluded that the content of soil-size particles is usually sufficient on most spoilbanks studied (Byrnes and Miller 1973; Plass and Vogel 1973; Cummins et al. 1965; Hart and Byrnes 1960; Einspahr et al. 1955; and Bramble 1952).

Texture is defined as the relative proportion of various size groups of mineral particles that are less than 2 mm in diameter (Limstrom 1960). Generally, spoilbanks composed of loams and silty materials are the most productive, as they provide growth media with favorable aggregation, drainage, aeration, available nutrients, and moisture. Spoils containing a high percentage of sand are well aerated, but lack stability as well as the ability to hold water during periods of drought. Clay spoils exhibit the most difficult condition for plant growth because of their poor drainage and aeration, compaction, and crusting over during dry periods (United States Department of Agriculture 1964).

A recent study showed that 63, 27, and 10 percent of the spoil materials in Illinois was predominately silt, clay, and sand, respectively (Haynes and Klimstra 1975). Grandt and Lang (1958) reported that 27 of 39 samples from surface-mined land in Illinois were silty clay loams, silty clays, or clay loams. Einspahr et al. (1955) noted that spoil materials in Iowa were predominately silty clay loams or loam. Spoilbanks in the eastern Kentucky coal field have been classified either as loam or clay loam (Cummins et al. 1965).

Although difficult to distinguish from the effects of texture and other site factors, aggregation (arrangement or organization) of spoil

materials affects water movement, erosion, and productivity. During the mining process, the materials overlying the coal are broken into fragments, thereby altering the aggregation of the original soil (Limstrom 1960). Spoils that are newly formed or nonvegetated generally reflect looser structures than those that are vegetated. Grading can be expected to increase compaction (Limstrom 1960; Wilson 1957). Limstrom (1960) considered only two types of aggregation in classifying surface-mined land for tree planting; these were "loose" and "compact," which denoted the capacity of the spoil particles to hold together. The majority (78 percent) of the spoil material in Illinois has been classified as loose (Haynes and Klimstra 1975).

Although physical factors play an important role in the establishment and growth of vegetation, it has been generally held that problems of nutrient deficiency, toxicity of certain elements, and adverse chemical reactions are most often the cause of vegetational failures on acid spoil (Chadwick 1973; Knabe 1965).

## Chemical Properties

The degree of acidity and alkalinity (pH) of a soil solution is considered one of the most important indicators of potential productivity of surface-mined land (Limstrom 1960; Croxton 1928). Limstrom's (1948) widely-accepted method of classification of surface-mined land based on pH and texture designates spoil materials as toxic when pH is less than 4.0 over more than 75 percent of the area sampled. Based on these criteria, Limstrom and Deitschman (1951) classified as toxic 1 percent (416 of 39,820 acres surveyed in 1945-46) of the surface-mined land in Illinois. Grandt and Lang (1958) reported that approximately 5 percent of 2,035 samples

taken from 15 counties in Illinois exhibited a pH of 4.0 or less. Haynes and Klimstra (1975) revealed that 3 percent (4,366 of 145,009 acres surveyed in 1970-71) of the spoilbank materials in Illinois showed a pH of 4.0 or less.

The pH of spoil material may influence nutrient absorption and plant growth either directly or indirectly. Below pH 4.0, the direct effect of excess hydrogen ions may be toxic or destructive to plant root tissues; however, many plants have been shown to tolerate variations in pH ranging from 4.0 to 9.0 as long as a proper balance of essential elements was maintained (Brady 1974; Arnon and Johnson 1942). Often of greater significance is the indirect effect of pH on availability of essential nutrients, solubility of certain toxic elements, and occurrence and abundance of microorganisms. Below a range in pH of 5.5 to 5.0, elements such as iron, manganese, aluminum, zinc, copper, and cobalt enter into solution at concentrations toxic to many plants. Conversely, these elements become less available as the pH is raised from 5.0 to 7.5 or 8.0. The availability of potassium and molybdenum is greatest when the pH is above 6.0; calcium and magnesium exhibit their greatest availability when the pH ranges from 6.0 to 8.5. Although phosphorus is never readily soluble in the soil, it is most available to plants when the pH ranges from 6.0 to 7.0. Available nitrogen and sulfur are maximum when pH is above 5.5. Boron is most soluble under acid conditions ranging from pH 5.0 to 6.9. At pH values greater than 8.0, bicarbonate ions may interfere with the normal uptake of some ions (Brady 1974:387-390).

It is commonly recognized that most bacteria and actinomycetes function best when soil pH is above 5.5. Furthermore, microorganisms involved

in nitrification and nitrogen fixation function only at pH values above 5.5 (Brady 1974:390; Wilson 1965). Fungi are considered to be versatile and are usually found at all values of pH. Some fungi prevail when the pH is less than 5.5; these are able to effect certain enzymatic transfers that result in release of ammonium ions, which are readily available to most higher plants. Also, microorganisms that oxidize sulfurous compounds to sulfuric acid function vigorously under low pH values where they receive little competition from other acid-sensitive types (Brady 1974:390-391; Limstrom 1960). In summary, values of pH ranging from 6.0 to 7.0 are the most suitable for promoting the availability of plant nutrients and the activity of most soil microorganisms.

Much of the plant mortality occurring on surface-mined land has been attributed to toxicity resulting from high concentrations of sulfuric acid and soluble salts. Most of the acidity originates from the oxidation of pyrite ($FeS_2$) when exposed to air and moisture; hence, the primary factors that determine total potential acidity are the amount of pyritic material in the overburden and its placement during the mining (Struthers 1964; Limstrom 1960; and Croxton 1928). Numerous other physical, chemical, and biochemical factors affect the rate of acid production and release of acid in the spoil (Anon. 1971; Smith and Shumate 1971; Singer and Stumm 1970; Coal Industry Advisory Committee 1964; Silverman and Ehrlich 1964; Limstrom 1960; and Limstrom and Deitschman 1951).

In some cases, the concentration of acid in spoilbanks becomes so great that water vapor is attracted hygroscopically from the atmosphere; during dry periods such acid surfaces appear as dark, wet spots. Also, spoils lacking visible acid spots may be highly acid; and, both

acid and basic conditions can be encountered only small distances apart (Wilson 1965; Limstrom 1960; and Wilson and Hedrick 1959). If sufficient limestone and other basic materials are present in the spoil, the acidity is neutralized. Weathering, leaching, and runoff may also gradually reduce the acidity in some areas; but, the exposure of new pyritic surfaces to oxidation and further acid formation is more likely to prolong acidity (Struthers 1964; Limstrom 1960).

The chemical reactions associated with pyrite oxidation have been elaborated by previous investigators. Singer and Stumm (1970) and Silverman and Ehrlich (1964) described these reactions as follows:

1) $FeS_2 + 2O_2 \longrightarrow Fe^{2+} + SO_4^{2-} + S$

2) $FeS_2 + 3\frac{1}{2}O_2 + H_2O \longrightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$

3) $Fe^{2+} + \frac{1}{4}O_2 + H^+ \rightleftharpoons Fe^{3+} + \frac{1}{2}H_2O$

4) $FeS_2 + Fe^{3+} \longrightarrow 3Fe^{2+} + 3SO_4^{2-} + 2S$

5) $S + 1\frac{1}{2}O_2 + H_2O \xrightarrow{\text{bacteria}} 2H^+ + SO_4^{2-}$

6) $Fe^{3+} + 3H_2O \longrightarrow Fe(OH)_3 + 3H^+$.

Equations (1) and (2) are initiator reactions, which release ferrous iron ($Fe^{2+}$). Equations (3) and (4) depict a cycle of oxidations and reductions in which ferric ($Fe^{3+}$) and ferrous iron are generated. In addition to oxygen, ferric iron serves as an oxidant of pyrite [Equation (4)]. Singer and Stumm (1970:1,121-1,123) have demonstrated that ferric iron is the major oxidant of pyrite; also, they considered the oxidation of ferrous to ferric iron to be the rate-limiting step in the production of acid from pyritic materials.

Most researchers have stressed the importance of the iron-oxidizing bacteria of the genus Thiobacillus as a catalyst in the oxygenation of ferrous to ferric iron. In the absence of these bacteria, the oxygenation

of ferrous iron has been considered to proceed too slowly to be of any consequence in the production of acidity in mine systems (Singer and Stumm 1970; Silverman and Ehrlich 1964). Bacteria of the genus Thiobacillus are also known to catalyze a much slower oxidation of inorganic sulfur to sulfuric acid as depicted in equation (5) (Brady 1974; Silverman and Ehrlich 1964). Furthermore, bacteria are probably involved in the direct, oxidative attack on metal sulfide minerals independent of the action of ferric iron (Silverman and Ehrlich 1964:181). However, Smith and Shumate (1971:15) state that the role of microbial catalysis in such a reaction has no significant bearing on the rate of formation of acid mine drainage.

Equation (6) represents the precipitation of ferric iron as ferric hydroxide, which results in the familiar red color often observed in acid waters (Smith and Shumate 1971).

A high concentration of soluble salts in growth media is associated with high acidity resulting from the oxidation of sulfide materials such as pyrite. Berg (1965) and Struthers (1964) have noted that on acid spoils the concentration of soluble salts and the plant growth are inversely related. High concentrations of soluble salts in growth media may be detrimental to plants by preventing seed germination, growth, or water uptake. When the osmotic potential of spoil solution is high, water may actually move out of the plant tissues resulting in the collapse of cells within the plant (Brady 1974; Berg 1965). However, Berg (1965) found that although liming of acid spoils eliminated toxicity to plants, the amount of soluble salts was only slightly less than before treatment. These results indicated that toxic conditions were due to an increased concentration of certain toxic ions brought into solution when pH dropped below 5.5.

Struthers (1964) studied the chemical weathering of spoil material in Ohio and reported that total soluble salts were much greater in toxic (pH less than 3.0) than in nontoxic samples. Toxic samples revealed high amounts of soluble aluminum, iron, and manganese salts (mostly sulfates). Also, calcium and magnesium were limited and leached rapidly from the spoil; and, there was a characteristically low calcium to magnesium ratio. The major component of the salt from nontoxic samples was calcium, while cations of aluminum, manganese, and iron were relatively minor components.

Other researchers have demonstrated consistently the presence of high concentrations of soluble iron, manganese, aluminum, and sulfates in acid and poorly vegetated spoil materials (Berg and Vogel 1973; Massey and Barnhisel 1972; Barnhisel and Massey 1969; Berg 1965; Cummins et al. 1965; and Wilson and Hedrick 1959) thereby suggesting that excess amounts of these elements in solution bring about plant toxicity. Berg and Vogel (1973, 1968) have demonstrated characteristic symptoms of manganese and aluminum toxicity on several species of legumes grown in extremely acid spoil material. Although toxic amounts of other elements such as copper, zinc, and nickel may occur on acid spoils (Berg and Vogel 1973; Massey 1972; Massey and Barnhisel 1972; Barnhisel and Massey 1969; and Berg 1965), excess concentrations of aluminum and manganese in solution are likely to be the primary cause of plant mortality (Berg 1965).

Brady (1974:25) has pointed out that organic matter, nitrogen, and phosphorus are likely to be critical to plant growth in almost all mineral soils. Organic matter and nitrogen, originally present in small amounts, are lost readily through oxidation, leaching, or crop removal. Phosphorus exhibits low availability to higher plants as well as small amounts present in most mineral soils.

In newly-formed spoil material lacking vegetation, the amount of organic matter and available nitrogen is practically nil. This condition persists in toxic and barren spoils; but, on spoils capable of becoming vegetated with leguminous and other plants, levels of these components generally increase within a few years (Beyer and Hutnik 1969; Horn and Ward 1969; Cummins et al. 1965; Wilson 1965; Limstrom 1960; Wilson and Hedrick 1957; Einspahr et al. 1955; and Limstrom and Deitschman 1951).

Wilson (1965) reported that the addition of organic matter to spoil material influenced both the number and types of organisms. When the organic material had a narrow carbon to nitrogen ratio (as in alfalfa), a more positive influence on the microflora was demonstrated than when the organic material had a wide carbon to nitrogen ratio (as in straw). The decomposition of organic matter occurred even in strongly acid spoils; but, it was enhanced by the addition of nitrogen.

Analyses of spoil material from the Central States have shown that available phosphorus ranges from low to very high when compared to agricultural standards (Berg 1973; Plass and Vogel 1973; Berg and May 1969; Beyer and Hutnik 1969; Horn and Ward 1969; Cummins et al. 1965; Hart and Byrnes 1960; Einspahr et al. 1955; and Grandt and Lang 1958). However, levels of available phosphorus are often greater in spoil material than on unmined lands (Limstrom 1960; Birkenholz 1958). Grandt and Lang (1958) reported that the phosphorus content of forage grown on Illinois surface-mined lands was high compared to that of forage grown on Illinois farm soils; these results demonstrated a close association between high available phosphorus shown by the soil tests and the high phosphorus content of the forages.

In acid spoil materials that exhibit high concentrations of soluble aluminum, the availability of phosphorus can be a limiting factor for many species of plants. Both aluminum and phosphate accumulate in the roots resulting in an induced phosphate deficiency in the top parts of affected plants; this suggests a physical blockage by precipitation (Jones 1961; Wright 1945; and Wright 1943).

Croxton (1928) recognized that fertility of spoilbank materials was linked with a complex of factors and conditions affecting cation exchange capacity. Brady (1974:598) has defined cation exchange capacity as "the sum total of exchangeable cations that a soil can absorb," which is "expressed in milliequivalents per 100 grams of soil (or of other adsorbing material such as clay)." A milliequivalent is "1 milligram of hydrogen or the amount of any other ion that will combine with or displace it" (Brady 1974:101).

Most of the potassium, calcium, magnesium, and sodium exists in the soil in inorganic forms. These, and several other cations, are adsorbed by the colloidal complex of the soil and are held or released depending upon a number of factors such as texture, amount and kind of clay, organic matter context, pH, proportion of the total exchange sites occupied by given cations, and the influence of associated ions (Brady 1974:26-28, 103-109).

In spoil materials that are not highly acid, amounts of some exchangeable nutrients are adequate for plant growth; and, in many areas the amounts of these nutrients are greater than on adjacent, unmined lands (Berg 1973; Struthers 1964; Limstrom 1960; Birkenholz 1958; Grandt and Lang 1958; Einspahr et al. 1955; and Limstrom and Deitschman 1951). However, in highly acid and toxic spoil materials the situation is quite

different. Struthers (1964) reported that the calcium to magnesium ratio and exchangeable potassium were low in spoil materials from Ohio. Byrnes and Miller (1973) noted that spoils in Indiana exhibited low amounts of exchangeable potassium.

A study (Cummins et al. 1965) of acid spoil materials in eastern Kentucky showed a low calcium to magnesium ratio, low to very low exchangeable calcium, abundant exchangeable magnesium and sodium, and low to adequate amounts of exchangeable potassium. Although the total cation exchange capacity ranged from 5 to 27 meq/100 g as compared with 17 to 30 meq/100 g in agricultural soils of the region, the exchangeable hydrogen contributed (primary source of reserve acidity) 50 percent or more of the exchangeable cations for 30 percent of the samples. Research by Barnhisel and Massey (1969) yielded similar results with some slight differences for potassium and exchangeable magnesium.

Toxic spoil materials from Pennsylvania have exhibited cation exchange capacities and levels of exchangeable hydrogen and aluminum which were higher than corresponding values from nontoxic spoils. Also, low calcium to magnesium ratio and low exchangeable calcium, magnesium, and potassium were exhibited. Exchangeable manganese was higher in nontoxic samples than in toxic ones (Beyer and Hutnik 1969; Horn and Ward 1969).

In summary, spoilbank materials are typically a heterogeneous mixture with their physical and chemical properties determined originally by the thickness and composition of strata overlying the coal and the techniques employed to remove this overburden. Changes in the properties of these materials depend on a complex of interacting factors. In general, most spoilbanks reveal physical properties within the range of tolerance of many plants. Several years after mining, spoils having a pH above 5.0 or

5.5 will show adequate organic matter and nitrogen for numerous species of plants. Generally other nutrients are present in adequate amounts, often exceeding that of unmined land. For spoil materials that exhibit a pH less than 5.5 or 5.0, the following chemical properties can be expected with regard to agricultural standards:

1) Organic matter and available nitrogen practically nil

2) Low available phosphorus

3) High concentrations and possibly toxic levels of soluble aluminum, manganese, iron, sulfates, copper, zinc, and nickel

4) A low calcium to magnesium ratio

5) Low exchangeable calcium

6) Variable amounts (ranging from low to adequate) of exchangeable potassium and magnesium

7) Abundant exchangeable manganese and sodium

8) High exchangeable acidity (exchangeable hydrogen plus exchangeable aluminum) and low base saturation (percentage of exchange sites occupied by cations other than hydrogen and aluminum).

Properties such as these constitute a harsh and often uninhabitable environment for many plants.

## METHODS AND MATERIALS

### Field Procedure

By interpreting aerial photographs in association with the field survey conducted between September 1970 and December 1971 (Haynes and Klimstra 1975), the affected acreage in each section was subdivided into units based on the following criteria:

1) Density and type of vegetation
2) Degree of grading
3) Type of utilization.

Using these criteria, one inspection site was visited for each discrete area. At each inspection site, a sampling point was located which appeared representative of most of the spoil material. This subjective decision was based on color, stoniness, and density of vegetation observed. It was frequently necessary to walk a short distance into an area before establishing a sampling point so as not to collect from the periphery which differed from the remaining area.

A sample of spoil material, collected from each inspection site by combining 5 to 10 soil-probe samples taken from the upper 6 inches of material, was sealed in a labeled plastic bag in the field-moist state and stored for later analysis. Using the same technique, one sample was collected from each solid slurry area and some gob piles. A total of 2,084, 17, and 5 samples of spoil, slurry, and gob, respectively, was collected during the study (Appendix, Tables A and B).

## Laboratory Procedure

After recording the number and location of each sample, all samples were sent to Nu-Ag Laboratories, Rochelle, Illinois, for determination of the following parameters:

1) Texture - percent sand, silt, clay
2) pH
3) Organic carbon - percent
4) Total nitrogen - ppm.
5) Available phosphorus - ppm.
6) Exchangeable potassium, calcium, magnesium, sodium, iron, manganese, hydrogen, and aluminum - meq/100 g
7) Total soluble salts - mmhos/cm
8) Soluble iron, manganese, aluminum, and sulfate - ppm.

Samples were dried, sieved, and ground by Nu-Ag Laboratories as described by Jackson (1958:30-36).

Percent of sand, silt, and clay was determined by the Bouyoucos hydrometer method (Sabey 1969:21-23). The texture of each sample (class name) was obtained from the standard texture triangle (Fig. 2). A glass electrode pH meter was used to determine the pH's of 1 to 1 mixtures of spoil material to water (Peech 1965:920-923).

Organic carbon was measured by the Walkley-Black method, which is a wet-combustion technique based on spontaneous heating by dilution of sulfuric acid (Allison 1965:1,372-1,375). This method supposedly excludes most of the elemental carbon such as charcoal and coal while oxidizing the organic matter held in the soil-humus complex (Allison 1965:1,373; Jackson 1958:219). Because spoil materials often contain coal particles, this method should be advantageous. However, Wilson (1965:32) reported that

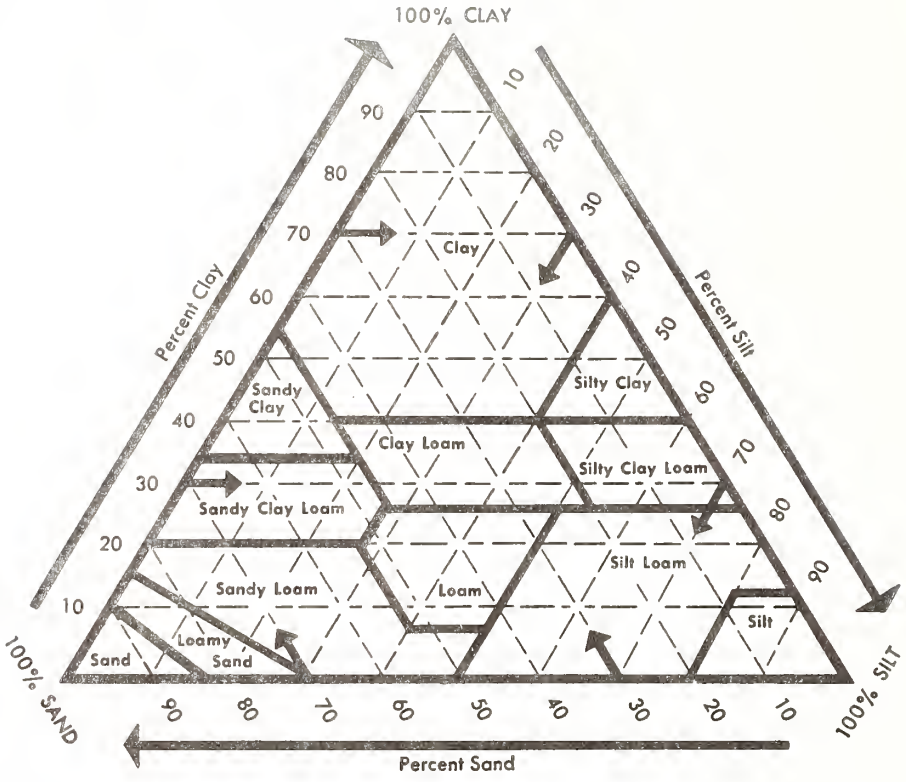


Fig. 2. Percentages of sand, silt, and clay in the basic soil textural classes. To obtain the textural class name, the laboratory-determined percentages are located on the triangle; then, percentage lines are followed until they intersect (United States Department of Agriculture 1951:209).

coal separated from some spoils was oxidized heavily during the wet combustion, while coal from other spoils was only slightly oxidized. The percent organic matter was calculated by using the conventional organic carbon to organic matter conversion factor of 1.724; this is based on the assumption that soil organic matter is 58 percent carbon (Jackson 1958:206).

Total nitrogen was determined by the Macro-Kjeldahl method modified to include nitrate and nitrite (Bremner 1965:1,162-1,165). This method involves the conversion of nitrogen to ammonium by digestion with concentrated sulfuric acid containing substances that promote this conversion; the ammonium is determined from the amount of ammonia gas liberated by the distillation of the digest with alkali. The amount of total nitrogen measured does not represent the amount of nitrogen available to plants (mostly inorganic ammonium and nitrate). The many attempts to develop accurate and efficient techniques for determination of available nitrogen have considerable disadvantages; and, none has proven to be completely reliable (Bremner 1965:1,179-1,185).

Phosphorus was extracted by the Bray ($P_1$) method, which uses a relatively weak acid-extracting solution (acid ammonium fluoride) to remove the adsorbed (or readily available) forms (Olsen and Dean 1965:1,040-1,041). This method has been most successful on acid soils and has been employed widely as an index of plant-available phosphorus (Olsen and Dean 1965).

Exchangeable calcium, magnesium, potassium, sodium, iron, and manganese were extracted by displacing the adsorbed ions with neutral 1 normal ammonium acetate. Titration with EDTA (ethylenediaminetetraacetate) was used to measure the amount of extracted calcium and magnesium (Chapman 1965:894-895; Heald 1965:1,003-1,008); exchangeable potassium and sodium were measured with a flame photometer (Pratt 1965a:1,025-1,026; Pratt

1965b:1,033-1,034). Atomic absorption was used to measure the concentrations of exchangeable iron and manganese. Water-soluble iron and manganese were determined separately and subtracted from the total (exchangeable plus water soluble) iron and manganese extracted with neutral 1 normal ammonium acetate. Hence, exchangeable iron and manganese represent the actual exchangeable forms and do not include the water-soluble fraction (Adams 1965:1,013-1,017; Olson 1965:967-968).

Exchangeable aluminum was obtained by extraction with neutral 1 normal potassium chloride (McLean 1965:985-988). Water-soluble aluminum was determined by following the suggested recommendations for extracting water-soluble manganese (Adams 1965:1,015); the concentrations of exchangeable and water-soluble aluminum were measured by atomic absorption.

Total acidity (meq $H^+$ and meq $Al^{3+}$) was determined by using SMP buffer solution as described by Shoemaker et al. (1961) and McLean et al. (1966). Exchangeable hydrogen was computed as the difference between total acidity and exchangeable aluminum.

Total soluble salts were determined by electrical conductivity of 1 to 2 soil-to-water extracts as measured by a Solu-Bridge. Results were expressed in mmhos/cm, which is the electrical conductivity times $10^3$ (Bower and Wilcox 1965:936-940; Jackson 1958:234-251).

The amount of acetate-soluble sulfate was obtained by the barium precipitation method described by Bardsley and Lancaster (1965:1,111-1,113).

## Data Analysis

Each of the 2,106 samples was coded as to type of material, region, county, coal seam, pH class, vegetation and age class, presence or absence of legumes, degree of grading, and type of utilization (Appendix, Table C).

Computer programs described by Nie et al. (1975) were used in conjunction with the IBM 370, Model 158 computer to sort data into the coded groups and calculate ranges, means, standard deviations, and frequency distributions.

A statistical test for significant difference between variables was not performed due to the following reasons:

1) Samples were not collected randomly and sampling intensity was probably too low; only one composite sample was collected from each discrete area regardless of its size (See Field Procedure, p. 16). It is well known that substantial variation occurs in spoil material from a given area (Limstrom 1960). Hence, samples were probably not representative of the actual conditions of the areas.

2) There were large differences in the total number of samples collected within each category (Appendix, Tables A and B).

3) The variance within groups of data was often excessively large. It is suspected that a significant portion of this variation probably resulted from deficiencies in the methods of laboratory analysis; most of these methods were developed for analysis of agricultural soils rather than for spoil material. High concentrations of certain ions present in highly acidic or alkaline spoil material are known to affect accurate determination of some plant nutrients (Smith et al. 1974:165-169; Chadwick 1973).

Caution in interpreting the results of these analyses is emphasized.

The hydrogen-ion activity of the spoil and refuse material was expressed as pH in aqueous suspension, or the negative logarithm of the hydrogen-ion concentration; mean pH values were calculated from individual pH determinations. Although a mean pH value is not equal to a mean of corresponding hydrogen-ion activities, expressing the hydrogen-ion activity as pH and calculating arithmetical averages of soil pH values have been widely adopted for convenience. Peech (1965:914-915) offers justification for use of average pH values based on the relationships between pH, lime requirements, and availability of plant nutrients.

The grouping of data according to regions was somewhat artificial. Limstrom and Deitschman (1951:206-220) divided 38,820 acres of surface-mined lands in Illinois into five districts based on differences in spoil conditions and other environmental factors that affected the choice of species for tree planting. Boyce and Neebe (1959:2-6) updated this classification by including lands surface mined subsequent to the survey by Limstrom and Deitschman (1951). Jewell and Haynes (1973) and Haynes and Klimstra (1975) further modified the classification by changing Adams and Schuyler counties from District I to Region III, and Livingston County from District II to Region I. These changes resulted in the formation of five regions that corresponded to the management regions of the Division of Land Reclamation, Illinois Department of Mines and Minerals (Fig. 3). According to E. E. Filer (personal communication), Supervisor, the management regions were established strictly for economical purposes even though they were similar to the five districts established by Limstrom and Deitschman (1951). The previously defined regions (Fig. 3) have been recently changed by the Division of Land Reclamation due to the addition of more operations under permit in different areas and the addition of new personnel. However, in order to integrate the results of this investigation with those by Haynes and Klimstra (1975), the five regions depicted in Fig. 3 have been maintained.

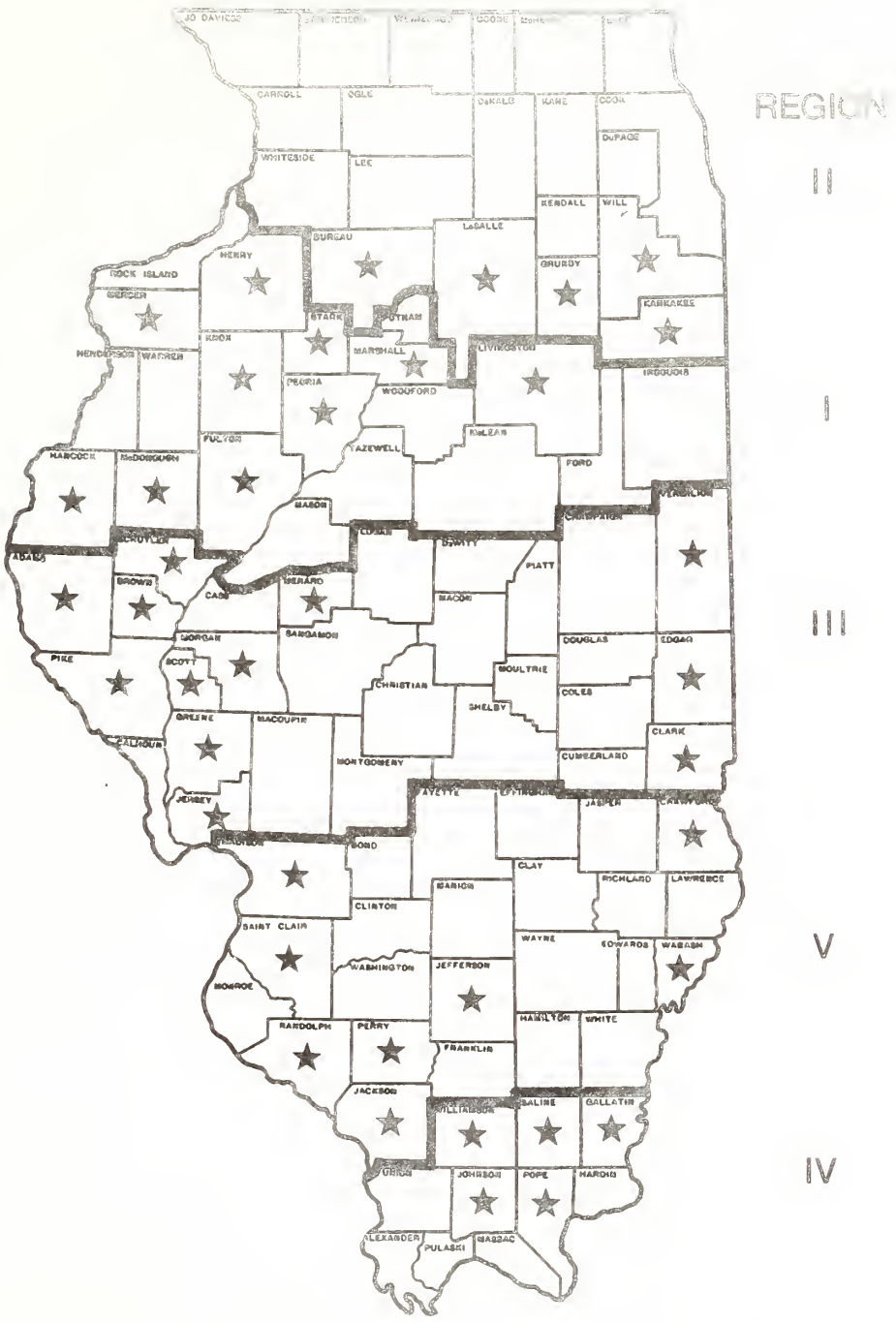


Fig. 3. Division of Illinois into five surface-mining regions (), and counties that exhibited surface mining for coal ( ) within each region (adapted from Haynes and Klimstra 1975).

## RESULTS AND DISCUSSION

### Spoil Characteristics Associated with Coal Seams

The Pennsylvanian strata in Illinois constitute the bedrock surface throughout nearly four-fifths of the State and have a maximum thickness of about 3,000 feet (Kosanke et al. 1960). Approximately 56 differently named coal seams are distributed through these strata with at least 36 seams known to be of strippable thickness, which is defined as coal in beds 18 inches or more thick with overburden not exceeding 150 feet (Searight and Smith 1969; Smith 1968; Reinertsen 1964; Smith and Berggren 1963; Smith 1961; Kosanke et al. 1960; Smith 1958, 1957; Cady 1952; and Kay and White 1915). Most (98 percent) of the surface-mined land has resulted from the mining of six coal seams; the most extensively mined include LaSalle No. 2, Harrisburg and Springfield No. 5, and Herrin No. 6 (Table 1).

Environmental conditions that existed as the various rock strata and coal seams were formed and laid down have produced considerable variation in the proportion and arrangement of strata overlying the coal beds in Illinois (Kosanke et al. 1960). These differences and those associated with methods of mining and weathering processes, yield extensive variations in physical and chemical properties of spoilbank materials derived from mining the different coal seams.

The textures of Illinois spoilbank materials were variable; but, 95 percent of the samples reflected silt loam, sandy loam, and loam textures (Table 2). Because most soils of agricultural importance are a type of loam (Brady 1974), textures should not be limiting to the revegetation of

Table 1. Major coal seams surface mined within Illinois counties as of 30 June 1971 (adapted from Haynes and Klimstra 1975).

| County | Number of Coal Seam | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Unknown or Other | Total |
| | Acres | | | | | | | | |
| Adams | 0 | 228 | 0 | 0 | 0 | 0 | 0 | 0 | 228 |
| Brown | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 19 |
| Bureau | 0 | 0 | 0 | 0 | 0 | 3,125 | 0 | 10 | 3,135 |
| Clark | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| Crawford | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 |
| Edgar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 51 | 51 |
| Fulton | 0 | 3,678 | 0 | 0 | 32,083 | 4,753 | 10 | 0 | 40,524 |
| Gallatin | 0 | 0 | 0 | 0 | 249 | 1,131 | 0 | 103 | 1,483 |
| Greene | 0 | 56 | 0 | 0 | 0 | 0 | 0 | 0 | 56 |
| Grundy | 0 | 5,470 | 0 | 1,664 | 0 | 0 | 0 | 0 | 7,134 |
| Hancock | 0 | 101 | 0 | 0 | 0 | 0 | 0 | 0 | 101 |
| Henry | 3 | 2,599 | 0 | 0 | 0 | 74 | 0 | 0 | 2,676 |
| Jackson | 0 | 0 | 0 | 0 | 2,667 | 2,150 | 0 | 82 | 4,899 |
| Jefferson | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 387 | 387 |
| Jersey | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Johnson | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 50 |
| Kankakee | 0 | 2,160 | 0 | 0 | 0 | 0 | 0 | 0 | 2,160 |
| Knox | 0 | 60 | 0 | 0 | 2,861 | 14,489 | 0 | 0 | 17,410 |
| LaSalle | 0 | 1,213 | 0 | 0 | 0 | 0 | 0 | 0 | 1,213 |
| Livingston | 0 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 46 |
| Madison | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 7 |

Table 1. Continued

| County | Number of Coal Seam | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Unknown or Other | Total |
| | Acres | | | | | | | | |
| Marshall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| McDonough | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| Menard | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 |
| Mercer | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 |
| Morgan | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| Peoria | 0 | 2,218 | 0 | 0 | 33 | 3,936 | 0 | 0 | 6,187 |
| Perry | 0 | 0 | 0 | 0 | 0 | 20,317 | 0 | 0 | 20,317 |
| Pike | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Pope | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26 | 26 |
| Randolph | 0 | 0 | 0 | 0 | 1,549 | 4,225 | 0 | 0 | 5,774 |
| Saline | 0 | 0 | 1,047 | 0 | 2,161 | 5,501 | 78 | 1,171 | 9,958 |
| Schuyler | 0 | 249 | 0 | 0 | 1,815 | 0 | 0 | 0 | 2,064 |
| Scott | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Stark | 0 | 0 | 0 | 0 | 0 | 1,192 | 0 | 0 | 1,192 |
| St. Clair | 0 | 0 | 0 | 0 | 0 | 12,098 | 0 | 384 | 12,482 |
| Vermilion | 0 | 0 | 0 | 0 | 0 | 949 | 4,348 | 0 | 5,297 |
| Wabash | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 10 |
| Will | 0 | 5,971 | 0 | 0 | 0 | 96 | 0 | 0 | 6,067 |
| Williamson | 0 | 0 | 1,920 | 0 | 4,057 | 6,718 | 17 | 2,244 | 14,956 |
| Illinois | 28 | 24,080 | 2,967 | 1,664 | 47,475 | 80,754 | 4,453 | 4,540 | 165,961 |

Table 2. Texture of spoilbank materials as related to coal seams surface mined.

| Coal Seam | Average Texture[a] | No. of Samples | Distribution of Texture Class[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CL | SC | SL | SCL | Sd | SdCl | SdL | LS | L |
| | | | percent of samples | | | | | | | | |
| Rock Island No. 1 | L | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 50 |
| Colchester No. 2 | L | 240 | 6 | 0 | 35 | 1 | 1 | 1 | 22 | 2 | 32 |
| DeKoven and Davis No. 3 | L | 40 | 5 | 0 | 10 | 0 | 0 | 2 | 45 | 0 | 38 |
| Summum No. 4 | L | 8 | 0 | 0 | 25 | 0 | 0 | 0 | 50 | 0 | 25 |
| Harrisburg and Springfield No. 5 | L | 642 | 2 | 0 | 48 | 1 | 0 | 0 | 7 | 0 | 42 |
| Herrin No. 6 | L | 966 | 3 | 0 | 34 | 1 | 0 | 0 | 12 | 0 | 49 |
| Danville No. 7 | L | 45 | 0 | 0 | 11 | 0 | 0 | 2 | 27 | 0 | 60 |
| Unknown or Other | L | 30 | 0 | 0 | 16 | 0 | 0 | 3 | 22 | 0 | 59 |
| Percentage, All Samples | - | -- | 3 | < 1 | 37 | < 1 | < 1 | 1 | 13 | 1 | 45 |
| Total No. of Samples | | 1,977[b] | 60 | 1 | 736 | 16 | 3 | 9 | 262 | 8 | 882 |

[a]CL = clay loam, SC = silty clay, SL = silt loam, SCL = silty clay loam, SD = sand, SdCL = sandy clay loam, SdL = sandy loam, LS = loamy sand, L = loam.

[b]Due to insufficient soil, only 1,977 of 2,084 samples were analyzed for texture.

most spoilbank materials in Illinois. Haynes and Klimstra (1975) estimated that silt loam and loam textures were present on 63 percent of the spoils (91,043 acres); clay loam, silty clay, silty clay loam, and sandy clay loam comprised 27 percent (39,552 acres); and, sand, sandy loam, and loamy sand equaled 10 percent (14,414 acres).

Spoil materials resulting from the mining of all seams except Rock Island No. 1 and DeKoven and Davis No. 3 showed an average pH greater than 5.0 (Table 3); however, some surface materials from all seams exhibited a pH less than 4.4. Twelve percent of the samples yielded a pH less than 5.1, while 5 percent had a pH less than 4.1. Most (89 percent) samples revealed a pH ranging from 5.1 to 8.1 (Fig. 4).

Haynes and Klimstra (1975) estimated that 7 percent (10,643 acres) of the spoilbanks had a pH less than 5.1, while 3 percent (4,366 acres) exhibited a pH of 4.0 or less. About 63 percent of the surface materials that yielded a pH less than 5.1 was located in Region IV (Fig. 5), where Saline and Williamson counties contained 99 percent. LaSalle and Grundy counties (Region II) contained all spoils in this region with a pH less than 5.1, while most such spoils in Region V occurred in Jackson County. Regions I and II exhibited 260 and 455 acres, respectively, with a pH less than 5.1.

The exchangeable or reserve acidity (hydrogen and aluminum ions held on the colloidal particles) was highly variable among spoils of the various coal seams; values ranged from 0 to 40 meq/100 g of spoil material (Fig. 6). Generally, the exchangeable acidity occurring on agricultural soils in Illinois should not exceed 10 to 15 percent of the total cation exchange capacity (personal communication, E. C. Varsa, Department of Plant and Soil Science, Southern Illinois University at Carbondale); only spoil materials associated with the Harrisburg and Springfield, Herrin, and Danville seams

Table 3. pH of spoilbank materials as related to coal seams surface mined.

| Coal Seam | Average pH | Range in pH | No. of Samples | Distribution | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | pH < 3.1 | pH 3.1-4.0 | pH 4.1-5.0 | pH 5.1-6.0 | pH 6.1-7.0 | pH 7.1-8.0 | pH > 8.0 |
| | | | | percent of samples | | | | | | |
| Rock Island No. 1 | 4.2 | 3.8-5.0 | 6 | 0 | 50 | 50 | 0 | 0 | 0 | 0 |
| Colchester No. 2 | 6.6 | 2.1-8.0 | 253 | 3 | 9 | 7 | 6 | 16 | 59 | 0 |
| DeKoven and Davis No. 3 | 4.6 | 2.5-7.5 | 40 | 15 | 28 | 27 | 15 | 7 | 7 | 0 |
| Summum No. 4 | 6.5 | 3.1-7.6 | 8 | 0 | 12 | 0 | 12 | 12 | 62 | 0 |
| Harrisburg and Springfield No. 5 | 6.9 | 2.7-8.3 | 705 | 0 | 2 | 7 | 9 | 14 | 66 | 1 |
| Herrin No. 6 | 7.1 | 3.0-8.2 | 997 | 0 | 1 | 4 | 6 | 18 | 69 | 1 |
| Danville No. 7 | 7.1 | 4.3-8.0 | 45 | 0 | 0 | 7 | 9 | 16 | 69 | 0 |
| Other or Unknown | 5.1 | 3.2-7.7 | 30 | 0 | 23 | 40 | 10 | 7 | 20 | 0 |
| Percentage, All Samples | | | -- | 1 | 4 | 7 | 8 | 16 | 65 | 1 |
| Total No. of Samples | | | 2,084 | 15 | 74 | 141 | 158 | 331 | 1,349 | 16 |

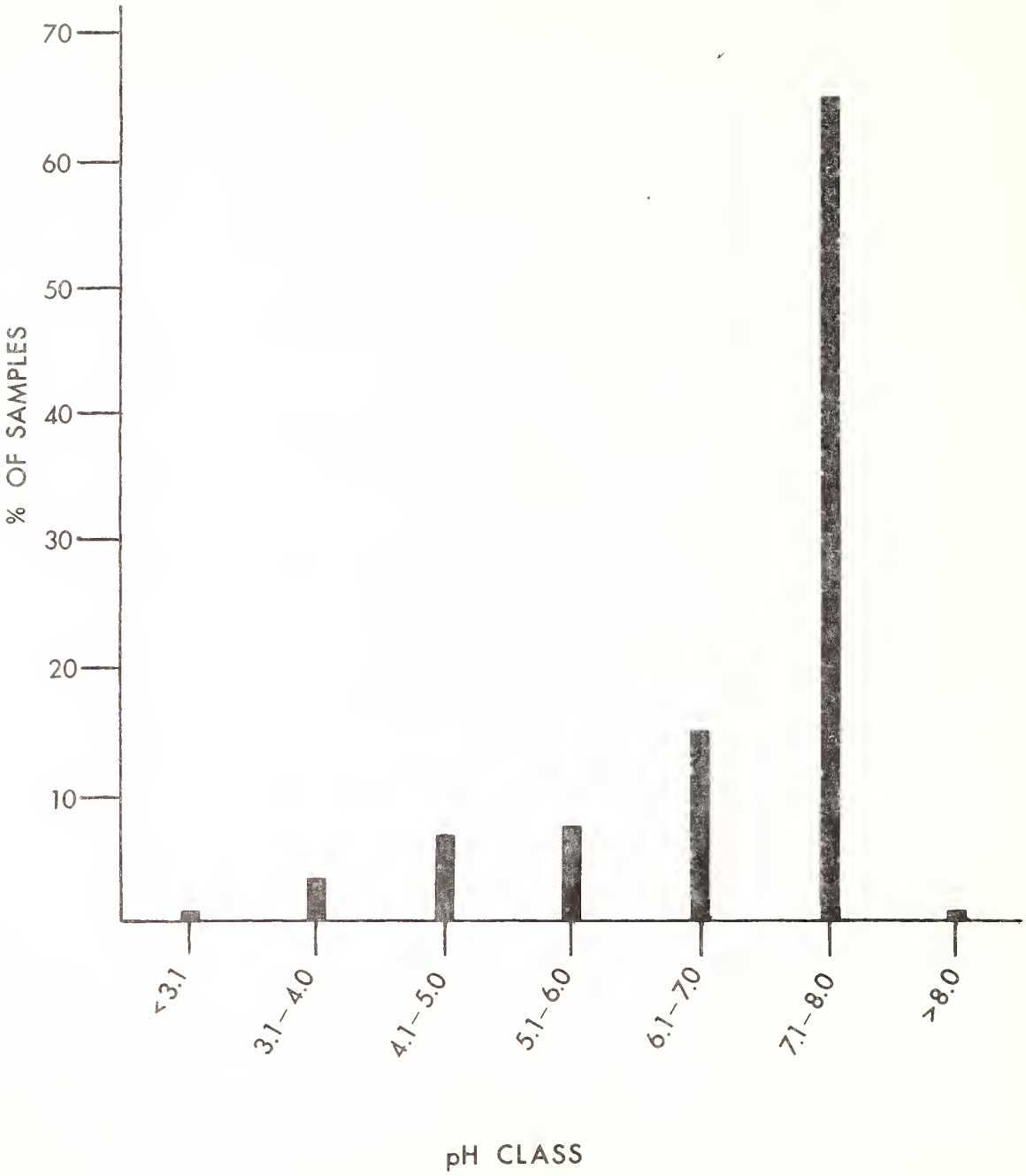


Fig. 4. Percentage of spoil samples distributed by pH class.

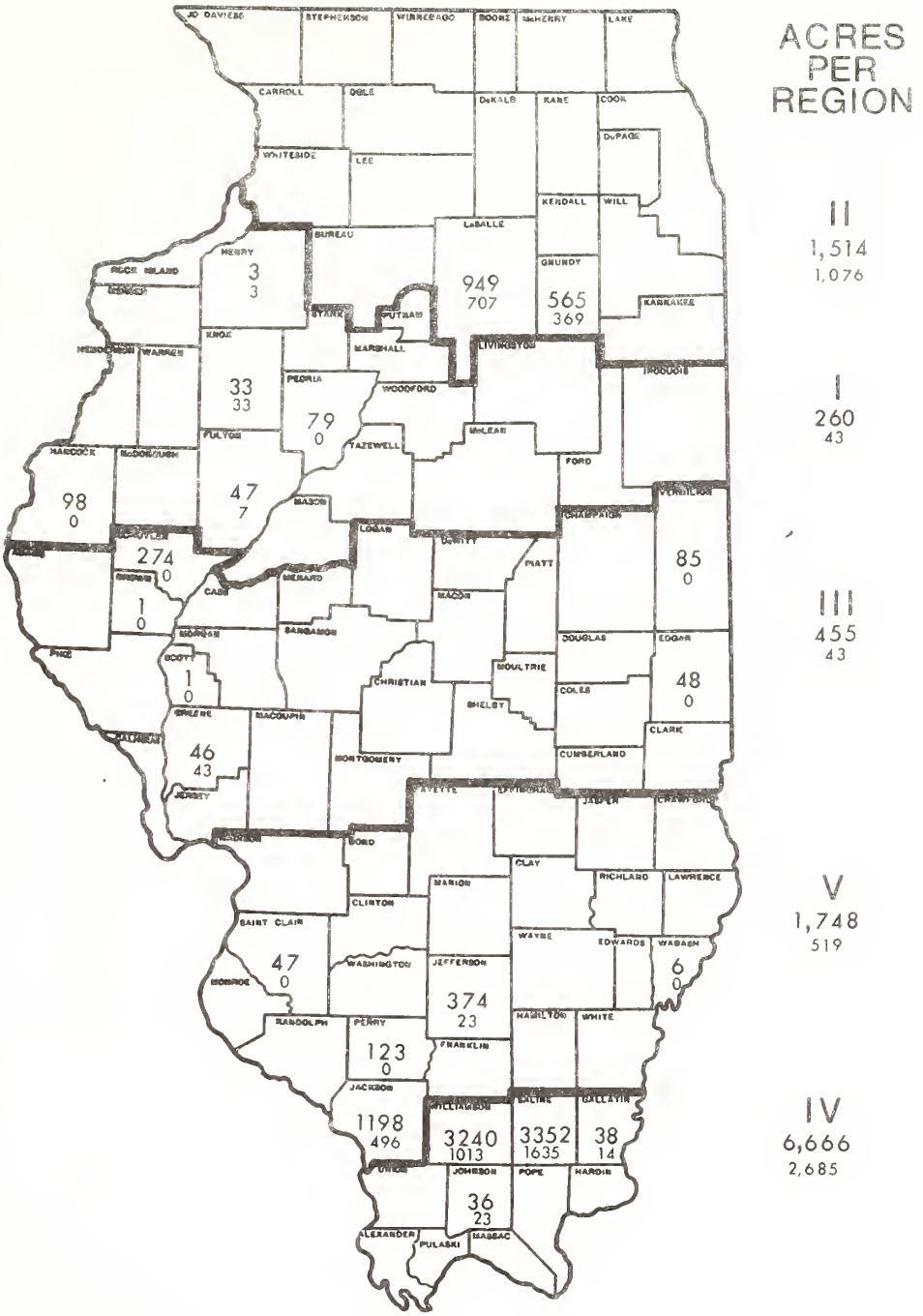


Fig. 5. Acreage of spoilbanks with a pH less than 5.1 (larger numerals) and less than 4.1 (smaller numerals), according to County and Region as of 30 June 1971 (adapted from Haynes and Klimstra 1975).

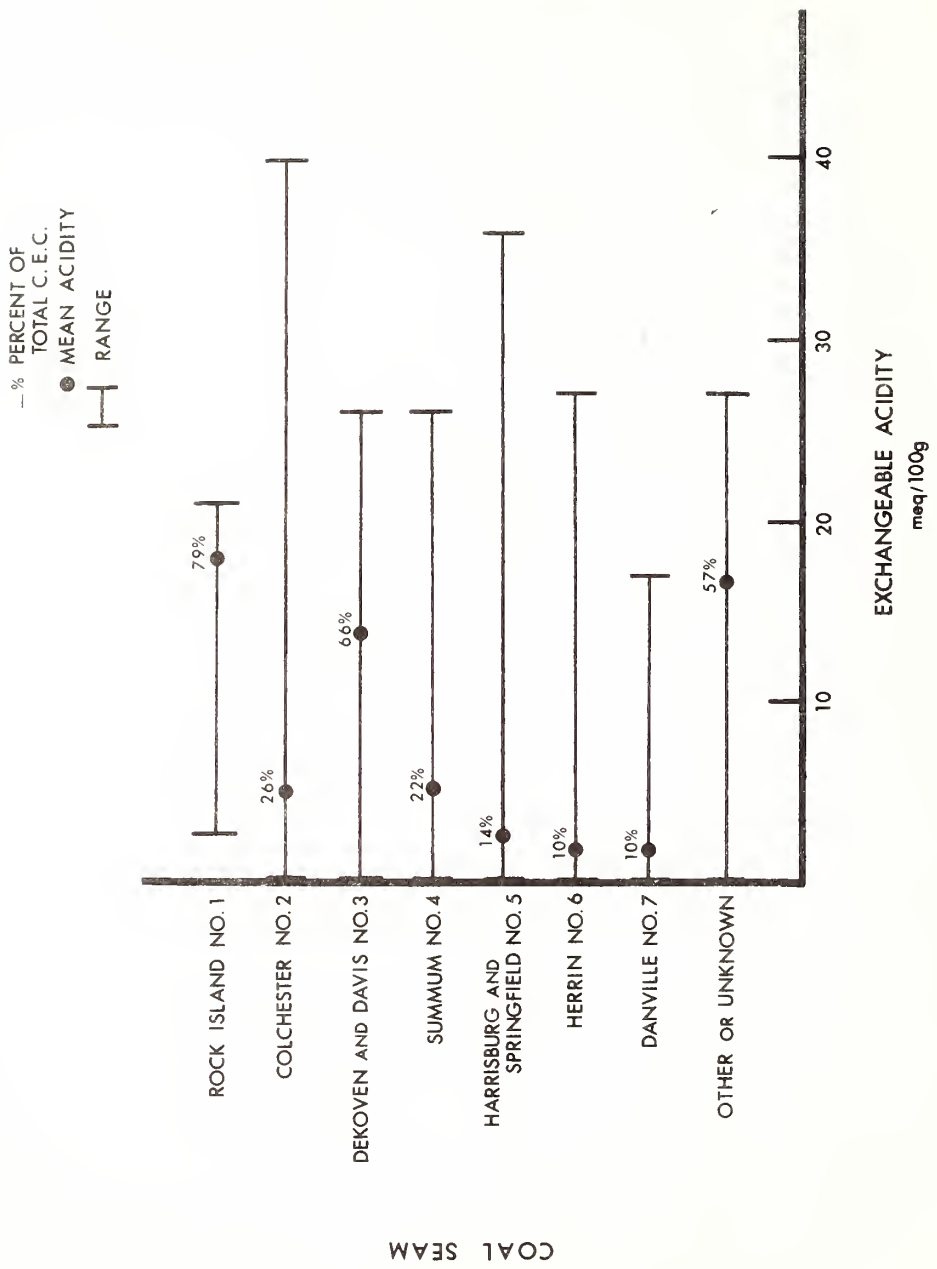


Fig. 6. Exchangeable acidity of spoilbank materials according to coal seams surface mined in Illinois.

were within this range. The highest average level of reserve acidity occurred on spoils that resulted from mining the Rock Island, DeKoven and Davis, and unidentified seams; these seams also showed the lowest average pH (Fig. 6 and Table 3).

Exchangeable acidity is an important factor to consider when identifying spoils that will be difficult to revegetate. As the active acidity (hydrogen-ion concentration in solution) of the soil solution is depleted, hydrogen and aluminum ions adsorbed on the colloidal particles move outward into the soil solution producing additional active acidity. Hence, the amount of lime needed to neutralize the active acidity may be very small--even at a low pH, but large amounts of lime would be required to neutralize spoils with a large exchangeable acidity (Brady 1974).

Surface materials that yielded a low pH and high reserve acidity were associated with every coal seam (Table 3 and Fig. 6); this indicates the presence and exposure of excessive amounts of acid-producing materials in these overburdens. Most of the highly acidic materials in Saline and Williamson counties (Region IV) resulted from mining of the DeKoven and Davis seams in southwestern Saline and southeastern Williamson counties and the Harrisburg seam. The close association of the DeKoven and Davis seams has resulted in mining of both seams simultaneously. The DeKoven coal is typically overlain by either gray to dark shale or by Palzo sandstone, while the Davis coal is commonly overlain by 4 to 6 feet of black shale (Smith 1957). The Harrisburg coal in southern Illinois is usually associated with large amounts of acid-producing pyritic materials (Smith 1957). Haynes and Klimstra (1975) noted that spoils which have resulted

from placement of these acid-forming materials on the surface represented some of the most toxic spoils in Illinois.

In LaSalle County (Region II), mining of the Colchester No. 2 seam often occurred in association with mining of refractory clay used in the manufacture of fire brick (Smith 1968). These clays were generally acidic, and most of the spoilbanks in LaSalle County were toxic and lacked vegetative cover. Also, mining of the Colchester coal in Grundy County (Region II) produced many spoils with a low pH.

Many coal beds not identified, or mined on a relatively small scale, commonly yielded surface materials with low pH and high reserve acidity (Table 3 and Fig. 6). Overburdens of these may have contained greater amounts of acid-forming materials than occurred in some of the larger and more widely distributed coal beds. Also, methods of mining used by smaller operations probably resulted in the placement of more toxic materials on the surface.

Levels of organic matter and nitrogen were highly variable (Table 4). Organic matter ranged from 0.0 through 14.5 percent, while nitrogen ranged from 1 through 9,828 ppm. Based on agricultural standards, mean values for organic matter and nitrogen were low (Table 5). Spoils from the Rock Island, DeKoven and Davis, and unidentified seams showed the lowest average values for organic matter; and, these seams plus the Danville revealed the lowest average levels of nitrogen.

Some portion of the observed variability in levels of organic matter and nitrogen may have resulted from the presence of coal particles in the samples. Total carbon determined by the Walkley-Black method (a wet-combustion technique) is supposed to exclude most of the elemental carbon such as coal, while oxidizing the organic matter held in the soil-humus

Table 4. Levels of organic matter, nitrogen, phosphorus, and exchangeable cations in spoilbank materials resulting from Illinois coal seams subjected to surface mining.

| Coal Seam | O.M. % | N[a] ppm. | P[b] ppm. | Exchangeable Ca meq/100 g | Exchangeable Mg meq/100 g | Exchangeable K meq/100 g | Exchangeable Na meq/100 g |
|---|---|---|---|---|---|---|---|
| Rock Island No. 1 | | | | | | | |
| Range | 0.7-2.1 | 392-1,036 | 3-21 | 0.58-2.50 | 0.67-3.74 | 0.11-0.23 | 0.20-0.37 |
| Mean | 1.2 | 690.7 | 8.5 | 1.72 | 2.18 | 0.19 | 0.33 |
| SD | 0.52 | 255.81 | 6.47 | 0.66 | 1.07 | 0.05 | 0.07 |
| Colchester No. 2 | | | | | | | |
| Range | 0.0-13.4 | 1-4,928 | 2-155 | 0.09-54.50 | 0.59-10.21 | 0.06-0.57 | 0.22-1.09 |
| Mean | 1.9 | 936.4 | 11.3 | 10.16 | 3.75 | 0.29 | 0.40 |
| SD | 1.37 | 560.06 | 14.13 | 6.65 | 1.94 | 0.11 | 0.09 |
| DeKoven and Davis No. 3 | | | | | | | |
| Range | 0.0-6.0 | 240-3,620 | 2-105 | 0.25-13.35 | 0.25-6.46 | 0.07-0.36 | 0.24-0.76 |
| Mean | 0.9 | 786.6 | 12.8 | 3.63 | 2.56 | 0.21 | 0.38 |
| SD | 1.21 | 723.46 | 18.44 | 3.23 | 2.13 | 0.07 | 0.10 |
| Summum No. 4 | | | | | | | |
| Range | 0.7-6.8 | 252-2,548 | 2-67 | 2.80-21.80 | 3.03-7.08 | 0.03-0.40 | 0.33-0.61 |
| Mean | 2.3 | 966.0 | 11.4 | 12.21 | 4.97 | 0.21 | 0.44 |
| SD | 1.98 | 698.64 | 22.52 | 5.23 | 1.59 | 0.13 | 0.09 |
| Harrisburg and Springfield No. 5 | | | | | | | |
| Range | 0.0-14.5 | 1-5,516 | 1-185 | 0.17-62.00 | 0.23-10.63 | 0.06-2.08 | 0.22-1.28 |
| Mean | 1.9 | 1,153.2 | 11.8 | 10.11 | 4.12 | 0.34 | 0.42 |
| SD | 1.69 | 699.71 | 15.77 | 4.69 | 1.67 | 0.15 | 0.11 |

Table 4. Continued

| Coal Seam | O.M. % | N[a] ppm. | P[b] ppm. | Exchangeable Ca | Mg | K | Na |
|---|---|---|---|---|---|---|---|
| | | | | meq/100 g | | | |
| Herrin No. 6 | | | | | | | |
| Range | 0.1-13.4 | 1-9,828 | 2-190 | 0.25-41.25 | 0.37-16.21 | 0.03-0.82 | 0.20-1.30 |
| Mean | 1.6 | 947.7 | 10.9 | 11.15 | 4.03 | 0.34 | 0.43 |
| SD | 1.29 | 612.21 | 12.97 | 4.03 | 1.76 | 0.10 | 0.14 |
| Danville No. 7 | | | | | | | |
| Range | 0.8-6.6 | 252-3,164 | 1-47 | 1.58-25.00 | 0.73-14.33 | 0.13-0.47 | 0.16-0.93 |
| Mean | 1.6 | 887.4 | 7.0 | 10.72 | 3.93 | 0.29 | 0.46 |
| SD | 0.96 | 498.91 | 8.17 | 4.95 | 2.59 | 0.08 | 0.16 |
| Other or Unknown | | | | | | | |
| Range | 0.5-4.6 | 252-1,708 | 2-38 | 0.58-13.70 | 0.84-8.96 | 0.06-0.50 | 0.15-1.13 |
| Mean | 1.5 | 900.8 | 16.9 | 5.63 | 3.10 | 0.24 | 0.45 |
| SD | 0.91 | 433.45 | 11.76 | 4.17 | 1.42 | 0.07 | 0.15 |

[a]Total nitrogen.

[b]Bray #1.

Table 5. Evaluation of soil tests for selected chemical parameters of agricultural surface soils.

| Test | Units | Evaluation |
|---|---|---|
| pH | Scale: 0-14 | pH < 4.0 - toxic to most plants; pH < 5.1 - may result in toxicity; pH 5.8 to slightly above 7.0 - optimum for most agricultural crops (Brady 1974:387-393) |
| Organic Matter[a] | % | Ranges from 0.4 to 10% in temperate-region mineral soils in U. S.; average of 4% (Brady 1974:24) |
| Total Nitrogen | ppm.[b] | Surface layer of most cultivated soils contains between 200 and 5,000 ppm.; average of 1,500 ppm. (Brady 1974:24) |
| Ratio: Organic Matter to Nitrogen | | About 20:1 in most soils tested (Brady 1974:155-156) |
| $P_1$ Phosphorus[c] | ppm. | Illinois - corn, soybeans, pasture legumes and grasses:<br><br>< 15 - low for all crops and soils;<br>15.5-25 - adequate;<br>> 25 - high (Graffis et al. 1973:41) |
| Cation Exchange Capacity (C.E.C.) | meq/100 g[d] | C.E.C. of surface horizon of most soils in midwest ranges from 10 to 35 meq/100 g (Sabey 1969: 57) |
| Exchangeable Potassium | meq/100 g[e] | Illinois - all crops:<br><br>< 0.31 - low<br>0.31-0.51 - optimum<br>> 0.51 - high (Graffis et al. 1973:41) |
| Exchangeable Calcium | meq/100 g[f] | Ranges from 6-16 meq/100 g; should occupy from 50 to 65% of the exchange complex (Brady 1974:105) |

Table 5. Continued

| Test | Units | Evaluation |
|---|---|---|
| Exchangeable Magnesium | meq/100 g[g] | Indiana:<br>< 0.31 - inadequate[h] for light-colored, coarse-textured soils;<br>> 0.31 - adequate<br>< 0.41 - inadequate[h] for light-colored, medium to fine-textured soils;<br>> 0.41 - adequate (Purdue University 1973:4) |
| Ratio: Calcium to Magnesium | | Should not exceed 10:1 or be < 1:1[i]; 6.5:1 considered optimum for agricultural soils in New Jersey (Bear and Toth 1948:69) |
| Exchangeable Sodium | meq/100 g[j] | Southern Illinois:<br>Most soils range from 0.22 to 0.87[i] |
| Exchangeable Hydrogen and Aluminum | meq/100 g[k] | Illinois:<br>Should not exceed 10-15% of total C.E.C.[i] |
| Base Saturation | % | Illinois:<br>Should be between 84 and 96% of total C.E.C.[i] |
| Soluble Salts | mmhos/cm[l] | 0.0-0.4 - effects of salinity usually negligible;<br>0.4-0.8 - yield of very salt-sensitive crops may be restricted;<br>0.8-1.6 - yield of salt-sensitive crops restricted;<br>1.6-3.2 - only salt-tolerant crops yield satisfactorily;<br>> 3.2 - only a few salt-tolerant crops yield satisfactorily (Jackson 1958:244-251) |

Table 5. Continued

| Test | Units | Evaluation |
|---|---|---|
| Soluble Iron, Aluminum, Manganese, Sulfate | ppm. | High concentrations in solution may be toxic to plants when pH falls below 5.0 (Brady 1974:35) |

[a]Percent organic matter times 0.58 equals % organic carbon.

[b]Assuming an acre-furrow slice equals two-million pounds, ppm. times 2 equals lbs/acre.

[c]Also known as Bray phosphorus or readily available phosphorus.

[d]A milliequivalent (meq) is equal to 1 mg of hydrogen or amount of any other ion that will combine with or displace it.

[e]Meq potassium times 782 equals lbs/acre.

[f]Meq calcium times 401 equals lbs/acre.

[g]Meq magnesium times 244 equals lbs/acre.

[h]There is no conclusive research evidence in Indiana that yield or crop quality is always reduced when soil-test levels of magnesium are interpreted as inadequate.

[i]Personal communication, Edward C. Varsa, Department of Plant and Soil Science, Southern Illinois University at Carbondale.

[j]Meq sodium times 460 equals lbs/acre.

[k]Meq hydrogen times 20 equals lbs/acre.

[l]Millimhos (mmhos) per centimeter is equal to the electrical conductivity times $10^3$; table values represent those determined at 1:2 soil:water extract at 25°C with an estimated saturation moisture of 40%.

complex (Allison 1965). However, Wilson (1965) reported that coal from some spoils was heavily oxidized during the wet-combustion process, whereas coal from other spoils was only slightly oxidized. Furthermore, nitrogen is closely associated with organic carbon in soil and coal also contains nitrogen; hence, the presence of coal particles in the spoil could affect results obtained.

Phosphorus values ranged from 1 through 190 ppm.; and, interpretations based on agronomic cropping of soils reveal that mean levels were low in spoils of all seams except those from the unidentified seams (Tables 4 and 5).

Using spoil materials exhibiting a pH greater than 4.5 from southern Appalachian coal fields, Berg (1973) studied the relationship between plant growth and plant-available phosphorus as extracted by the Bray method (acid ammonium fluoride extractant). Spoils showing less than 4 ppm. of phosphorus were usually deficient in plant-available phosphorus, while those with over 8 ppm. were adequate for growth of herbaceous ground cover; grasses exhibited a variable response when levels of phosphorus were 4 to 8 ppm. On the basis of these indexes, phosphorus levels in Illinois (Table 4) would not be deficient; and, spoils from all seams except the Danville (mean of 7 ppm.) would be considered adequate for growth of herbaceous ground cover. This suggests caution in interpreting available phosphorus levels, as well as amounts of other plant nutrients. More studies are needed which correlate amounts of plant nutrients in spoil materials with plant response. Evaluations are further complicated by the fact that analyses for phosphorus, calcium, magnesium, and certain trace elements can be affected by interactions between high concentrations of various chemical species present in the samples and the chemical

extractant used to determine their availability (Smith et al. 1974; Berg 1973; Chadwick 1973; and Heald 1965).

Experimentation using spoil materials from West Virginia has revealed that extraction of phosphorus with acid ammonium fluoride provides satisfactory correlation with plant response when the pH of the material being tested is less than 6.5; but, when the pH is above 6.5, extractions using the Bray method are more erratic and may yield values that are too low (Smith et al. 1974). It was recommended that phosphorus be extracted by the sodium bicarbonate method, because determinations by this method correlate well with plant response both in acid and alkaline soils. Since 81 percent of the samples recorded in Table 3 exhibited a pH in the range of 6.1 to 8.1, levels of available phosphorus as determined by the Bray method (Table 4) may be lower than the true values.

Prominent cations of interest in soil fertility are calcium, magnesium, potassium, and sodium (Brady 1974:75). Except for sodium, amounts of each of these elements were highly variable in spoils from the different coal seams (Table 4). Based on agricultural standards, low mean values for calcium occurred in spoils of the Rock Island, DeKoven and Davis, and unidentified seams, while spoils of all seams had adequate average amounts of magnesium. All seams except for the Harrisburg and Springfield No. 5 and Herrin No. 6 revealed spoils with low average potassium levels; mean values for sodium were all within the range reported from agricultural soils in southern Illinois (Tables 4 and 5).

The average cation exchange capacity varied from 17.3 to 26.3 meq/100 g in spoils from the Danville and unidentified seams, respectively (Table 6). All values were within the range that commonly occurs in the surface horizon of most soils in the Midwest (Table 5). Percentage base saturation

Table 6. Mean cation exchange status and calcium to magnesium ratios in spoilbank materials resulting from Illinois coal seams subjected to surface mining.

| Coal Seam | Cation Exchange Capacity[a] | % Base Saturation | % Saturation of Complex With | | | | Ca:Mg[b] |
|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | K | Na | |
| Rock Island No. 1 | 22.3 | 22 | 8 | 10 | 0.9 | 1.5 | 0.8 |
| Colchester No. 2 | 19.6 | 84 | 52 | 19 | 1.5 | 2.0 | 2.7 |
| DeKoven and Davis No. 3 | 20.5 | 42 | 18 | 13 | 1.0 | 1.9 | 1.5 |
| Summum No. 4 | 23.2 | 88 | 53 | 21 | 0.9 | 1.9 | 2.5 |
| Harrisburg and Springfield No. 5 | 17.6 | 89 | 57 | 23 | 1.9 | 2.4 | 2.5 |
| Herrin No. 6 | 17.8 | 92 | 63 | 23 | 1.9 | 2.4 | 2.8 |
| Danville No. 7 | 17.3 | 92 | 62 | 23 | 1.8 | 2.8 | 2.7 |
| Unknown or Other | 26.3 | 48 | 21 | 12 | 0.9 | 1.7 | 1.8 |

[a]Meq/100 g spoil material.

[b]All ratios are cation-equivalent ratios.

and saturation of the exchange complex with calcium were low in spoils of the Rock Island, DeKoven and Davis, and unidentified seams; these seams also exhibited spoils with low average pH and high exchangeable acidity. Mean calcium to magnesium ratios were rather low in spoils from all seams; but again, the Rock Island, DeKoven and Davis, and unidentified seams revealed spoils with the lowest average values.

Total soluble salts as measured by electrical conductance (mmhos/cm) varied from 0.0 to 12.0 (Table 7). Some spoils of all seams exhibited concentrations that were detrimental to most plants (Table 5). The highest average concentration was found in the Summum spoils where values ranged from 0.2 to 4.1 mmhos/cm. Spoils from the Rock Island, Colchester, Summum, and unidentified seams showed mean values considered detrimental to the yield of salt-sensitive crops, while average values of spoils from all other seams were within the range considered restrictive to only very salt-sensitive crops (Tables 5 and 7).

Levels of soluble sulfate, iron, manganese, and aluminum were extremely variable (Table 7). Concentrations of these ions in solution are pH dependent; as pH falls below 5.5 or 5.0, their concentrations increase (Brady 1974:387-389). Because spoils from the Rock Island, DeKoven and Davis, and unidentified seams also showed the lowest average pH, they might be expected to yield the highest mean values for these soluble ions. Such a relationship was noted, but spoils of the Summum and Colchester seams (average pH of 6.5 and 6.6, respectively) showed relatively high mean concentrations of soluble sulfate, iron, and aluminum. Also, the DeKoven and Davis spoils (average pH of 4.6) exhibited a relatively low average concentration of soluble iron (Table 7). Hence, the extreme variability of soluble ion

Table 7. Levels of soluble salts in spoilbank materials resulting from Illinois coal seams subjected to surface mining.

| Coal Seam | Total Soluble Salts | Soluble | | | |
|---|---|---|---|---|---|
| | | $SO_4$ | Fe | Mn | Al |
| | mmhos/cm | ppm. | | | |
| Rock Island No. 1 | | | | | |
| Range | 0.1-2.3 | 21.8-348.0 | 1.8-11.2 | 3.0-8.6 | 2.4-288.0 |
| Mean | 0.8 | 201.5 | 3.5 | 4.7 | 81.7 |
| SD | 0.80 | 107.14 | 3.77 | 2.06 | 109.76 |
| Colchester No. 2 | | | | | |
| Range | 0.0-8.6 | 11.3-518.8 | 0.1-996.0 | 0.4-17.9 | 0.4-1,920.0 |
| Mean | 1.0 | 171.5 | 14.1 | 2.5 | 49.1 |
| SD | 1.04 | 133.18 | 65.58 | 2.90 | 204.25 |
| DeKoven and Davis No. 3 | | | | | |
| Range | 0.1-3.0 | 12.5-518.8 | 0.3-90.0 | 1.0-13.1 | 0.4-648.0 |
| Mean | 0.7 | 178.0 | 4.1 | 3.6 | 57.9 |
| SD | 0.65 | 136.97 | 14.12 | 2.81 | 127.99 |
| Summum No. 4 | | | | | |
| Range | 0.2-4.1 | 74.8-505.0 | 0.4-190.0 | 0.8-2.9 | 0.4-1,464.0 |
| Mean | 1.4 | 293.2 | 29.7 | 2.3 | 184.3 |
| SD | 1.62 | 177.97 | 65.08 | 0.74 | 517.07 |
| Harrisburg and Springfield No. 5 | | | | | |
| Range | 0.0-4.0 | 0.2-518.8 | 0.1-600.0 | 0.2-17.9 | 0.4-2,976.0 |
| Mean | 0.6 | 96.8 | 13.7 | 2.4 | 12.1 |
| SD | 0.60 | 103.99 | 43.56 | 3.01 | 122.12 |
| Herrin No. 6 | | | | | |
| Range | 0.0-12.0 | 0.2-505.0 | 0.1-998.0 | 0.2-17.9 | 0.4-1,080.0 |
| Mean | 0.6 | 92.5 | 12.0 | 2.0 | 7.1 |
| SD | 0.74 | 91.07 | 44.09 | 1.79 | 43.95 |
| Danville No. 7 | | | | | |
| Range | 0.0-3.8 | 13.8-397.5 | 0.6-92.0 | 0.6-11.2 | 0.4-56.7 |
| Mean | 0.7 | 124.8 | 6.7 | 1.7 | 3.8 |
| SD | 0.93 | 115.75 | 15.12 | 1.54 | 8.60 |
| Unknown or Other | | | | | |
| Range | 0.0-4.9 | 12.5-505.0 | 0.6-145.0 | 0.6-13.7 | 0.6-1,120.0 |
| Mean | 0.9 | 195.5 | 11.5 | 3.5 | 74.1 |
| SD | 1.23 | 151.6 | 15.72 | 2.61 | 246.72 |

concentrations within spoils of each seam tended to obscure relationships between coal seams, soluble salts, and pH.

Data presented herein provide information regarding the identification of spoils with adverse chemical and physical properties as related to the different coal seams. These are of value in predicting areas to be mined in the future which are likely to be difficult to revegetate unless care has been given to appropriate handling of the overburden. However, knowledge of the chemical and physical properties of the coal seam and each of the strata overlying the coal is essential. Such information should be obtained prior to any surface-mining effort. This is important so that combinations of overburden materials ensure the best medium for revegetation of disturbed acreages. Core-drill samples or exposed highwalls can provide this information.

Nearly 50 years ago, Croxton (1928) recognized the importance of identifying acid-producing strata prior to mining when attempting controlled placement of selected overburden materials. Numerous investigators since then have emphasized this concept (Despard 1974; Grube et al. 1974; McCormack 1973; Grube et al. 1973; Krause 1973; Berg and May 1969; May and Berg 1966; Limstrom 1960; Limstrom and Deitschman 1951; and Limstrom 1948). Most states now have regulations that require covering these materials and establishing suitable vegetative cover on the mined area. But, not all states require determination prior to mining which stratum or combination of strata contain materials best suited for plant growth. Obviously, the evaluation of overburden strata prior to mining coordinated with an adequate reclamation plan has more merit than attempting to correct a problem after it has occurred. Illinois lawmakers have incorporated most of these concepts into the Surface-Mined Land Conservation and Reclamation

Act (effective 17 September 1971 and amended by House Bill 1277, effective 1 July 1975) by requiring that applications for a mining permit contain the following information:

1) Nature, depth and proposed disposition of the overburden
2) Estimated depth to which the mineral deposit will be mined
3) Technique to be used in surface mining
4) Results of core drillings of consolidated materials in the overburden when required by the Department
5) A conservation and reclamation plan and map acceptable to the Department (Illinois Department of Mines and Minerals 1971, 1975b).

Furthermore, all mined areas that have an approved reclamation plan that calls for establishment of vegetation must be covered with soil or other material from the overburden capable of supporting plant growth in accordance with the reclamation plan and standards adopted by the Department of Mines and Minerals. The Department also has the authority to require that the darkened surface soil be segregated from the overburden during the mining process and placed on the surface subsequent to mining. This procedure is required only when deemed necessary to accomplish the requirements of the reclamation plan (Illinois Department of Mines and Minerals 1975b). Adherence to these requirements should insure that future surface-mined lands in Illinois will provide the best available growth medium for the type of vegetation called for in the reclamation plan.

## Relationship Between pH and Other Spoil Variables

Most of the textures in spoils of all pH classes were loam, silt loam, and sandy loam; relationships between pH and texture were not apparent (Table 8).

Table 8. Relationship of texture and pH for Illinois spoilbank materials resulting from surface mining for coal.

| pH Class | Average Texture[a] | No. of Samples | Distribution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Texture Class[a] | | | | | | | | |
| | | | CL | SC | SL | SCL | Sd | SdCL | SdL | LS | L |
| | | | percent of samples | | | | | | | | |
| < 3.1 | L | 15 | 13 | 0 | 27 | 0 | 0 | 0 | 13 | 7 | 40 |
| 3.1-4.0 | L | 72 | 4 | 0 | 23 | 0 | 0 | 6 | 20 | 0 | 45 |
| 4.1-5.0 | L | 134 | 5 | 1 | 26 | 2 | 0 | 1 | 18 | 0 | 49 |
| 5.1-6.0 | L | 148 | 10 | 0 | 30 | 0 | 0 | 0 | 13 | 0 | 48 |
| 6.1-7.0 | L | 313 | 4 | 0 | 28 | 0 | 0 | 1 | 16 | 0 | 51 |
| 7.1-8.0 | L | 1,281 | 2 | 0 | 42 | 1 | 0 | 0 | 11 | 0 | 43 |
| > 8.0 | SL | 14 | 14 | 0 | 43 | 7 | 0 | 0 | 0 | 0 | 36 |
| Percentage, All Samples | | -- | 3 | < 1 | 37 | 1 | < 1 | 1 | 13 | 1 | 45 |
| Total No. of Samples | | 1,977 | 61 | 1 | 734 | 16 | 3 | 8 | 256 | 7 | 891 |

[a]CL = clay loam, SC = silty clay, SL = silt loam, SCL = silt clay loam, Sd = sand, SdCL = sandy clay loam, SdL = sandy loam, LS = loamy sand, L = loam.

[b]Due to insufficient soil, only 1,977 of 2,084 samples were analyzed for texture.

Amounts of organic matter, nitrogen, and phosphorus were highly variable (Table 9). Average amounts of organic matter and nitrogen were low in all spoils (Table 5); but, except for those that showed a pH greater than 8.0, mean values were slightly less in spoils that exhibited a pH less than 5.1. No satisfactory explanation accounts for the low mean values for organic matter and nitrogen that occurred in spoils that revealed a pH greater than 8.0. Mean phosphorus levels were low in spoils that yielded a pH greater than 6.0, but were adequate to high in all others. Average phosphorus values tended to decrease as pH increased; the highest mean value occurred in spoils with a pH of 3.1 to 4.1. As previously discussed (p. 41) extraction of phosphorus with acid ammonium fluoride may have yielded values too low for spoils with a pH greater than 6.0.

A comparison of the spoils suggests that a pH less than 5.1 exhibited higher mean cation exchange capacities, exchangeable acidities, concentrations of exchangeable iron and manganese; and, lower mean base saturations and concentrations of exchangeable potassium, calcium, magnesium, and sodium (Fig. 7 and Table 10). The higher exchange capacities of the spoils with a pH less than 5.1 was mainly due to much higher exchangeable acidity (exchangeable hydrogen and aluminum). For potassium and calcium, average levels were low in these spoils, but were adequate in spoils that yielded a pH greater than 5.1. Average amounts of magnesium and sodium were sufficient in all spoils (Tables 5 and 10).

Although average calcium to magnesium ratios were low for all groups, spoils that exhibited a pH of less than 4.1 showed the lowest values. Also, organic matter to nitrogen ratios were low in spoils from all pH classes but were greatest within a range of pH from 4.1 to 8.1; the lowest mean ratios occurred in spoils with a pH less than 3.1 (Table 5 and Fig. 8).

Table 9. Relationship of pH with levels of organic matter, nitrogen, and phosphorus in spoilbank materials.

| pH Class | No. of Samples | O.M. % | N[a] ppm. | P[b] ppm. |
|---|---|---|---|---|
| < 3.1 | 11 | | | |
| Range | | 0.3-3.2 | 360-3,060 | 2-54 |
| Mean | | 1.0 | 983.6 | 23.2 |
| SD | | 0.86 | 747.70 | 18.38 |
| 3.1-4.0 | 66 | | | |
| Range | | 0.2-4.0 | 280-2,296 | 2-185 |
| Mean | | 1.4 | 903.1 | 27.9 |
| SD | | 0.82 | 389.80 | 31.08 |
| 4.1-5.0 | 141 | | | |
| Range | | 0.0-13.4 | 27-4,340 | 2-148 |
| Mean | | 1.5 | 886.1 | 18.7 |
| SD | | 1.58 | 505.45 | 19.61 |
| 5.1-6.0 | 158 | | | |
| Range | | 0.0-9.0 | 56-3,612 | 2-190 |
| Mean | | 1.8 | 1,051.2 | 20.1 |
| SD | | 1.44 | 584.16 | 25.50 |
| 6.1-7.0 | 331 | | | |
| Range | | 0.0-9.9 | 79-4,172 | 1-88 |
| Mean | | 1.9 | 1,035.8 | 11.2 |
| SD | | 1.45 | 638.21 | 10.23 |
| 7.1-8.0 | 1,349 | | | |
| Range | | 0.0-13.4 | 1-9,828 | 1-170 |
| Mean | | 1.7 | 1,009.2 | 8.5 |
| SD | | 1.28 | 643.03 | 8.42 |
| > 8.0 | 16 | | | |
| Range | | 0.3-3.4 | 185-1,900 | 2.11 |
| Mean | | 0.7 | 473.8 | 4.3 |
| SD | | 0.74 | 407.32 | 2.27 |

[a]Total nitrogen.

[b]Bray #1.

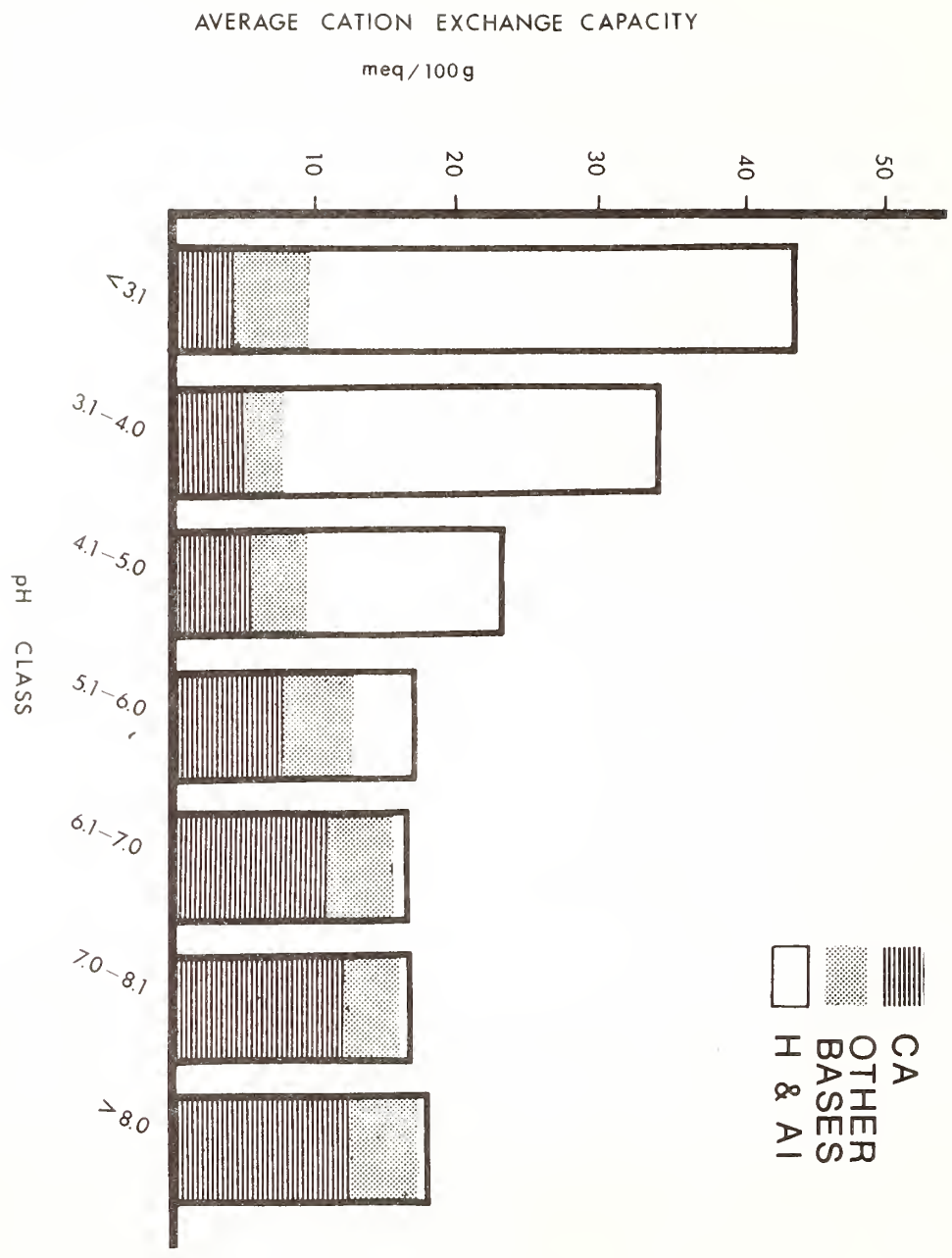


Fig. 7. Relationship between average percentage base saturation, exchangeable calcium and other bases, and mean cation exchange capacity according to pH class of spoilbank materials.

Table 10. Relationship of pH with levels of exchangeable cations in spoilbank materials.

| pH Class | Exchangeable K | Ca | Mg | Na | Fe | Mn | H | Al |
|---|---|---|---|---|---|---|---|---|
| | meq/100 g | | | | | | | |
| < 3.1 | | | | | | | | |
| Range | 0.04-0.16 | 0.09-21.20 | 0.25-8.96 | 0.24-0.50 | 0.035-2.041 | 0.022-0.833 | 17.0-40.0 | 1.61-23.36 |
| Mean | 0.10 | 4.04 | 2.69 | 0.37 | 0.406 | 0.216 | 26.30 | 9.30 |
| SD | 0.04 | 6.13 | 2.81 | 0.09 | 0.67 | 0.24 | 5.76 | 7.22 |
| 3.1-4.0 | | | | | | | | |
| Range | 0.03-0.36 | 0.17-14.05 | 0.23-10.63 | 0.15-0.57 | 0.005-1.396 | 0.004-0.945 | 10.4-28.0 | 0.00-16.46 |
| Mean | 0.18 | 4.59 | 2.88 | 0.36 | 0.068 | 0.252 | 19.90 | 5.83 |
| SD | 0.08 | 3.61 | 2.45 | 0.08 | 0.23 | 0.25 | 4.03 | 3.44 |
| 4.1-5.0 | | | | | | | | |
| Range | 0.10-0.79 | 0.58-41.25 | 0.33-13.42 | 0.20-0.96 | 0.004-0.059 | 0.018-0.881 | 0.0-24.0 | 0.17-10.12 |
| Mean | 0.26 | 5.58 | 2.64 | 0.38 | 0.021 | 0.188 | 11.13 | 3.09 |
| SD | 0.09 | 5.09 | 2.04 | 0.10 | 0.01 | 0.17 | 5.48 | 1.97 |
| 5.1-6.0 | | | | | | | | |
| Range | 0.07-1.49 | 1.38-62.00 | 0.67-16.21 | 0.16-1.28 | 0.004-0.097 | 0.015-0.913 | 0.0-24.0 | 0.06-14.02 |
| Mean | 0.33 | 7.69 | 3.92 | 0.43 | 0.022 | 0.138 | 3.79 | 0.78 |
| SD | 0.14 | 5.92 | 2.24 | 0.17 | 0.01 | 0.14 | 3.28 | 1.31 |
| 6.1-7.0 | | | | | | | | |
| Range | 0.13-0.75 | 1.75-40.00 | 0.89-10.67 | 0.23-1.30 | 0.003-0.082 | 0.004-0.482 | 0.0-19.0 | 0.00-5.06 |
| Mean | 0.33 | 10.55 | 4.18 | 0.43 | 0.020 | 0.057 | 0.34 | 0.35 |
| SD | 0.09 | 4.82 | 1.87 | 0.14 | 0.01 | 0.05 | 1.49 | 0.32 |
| 7.1-8.0 | | | | | | | | |
| Range | 0.11-2.08 | 1.58-45.75 | 0.59-13.88 | 0.20-1.28 | 0.001-0.068 | 0.004-0.594 | 0.0-4.6 | 0.00-2.45 |
| Mean | 0.35 | 11.52 | 4.14 | 0.43 | 0.021 | 0.043 | 0.01 | 0.36 |
| SD | 0.12 | 3.65 | 1.55 | 0.12 | 0.01 | 0.04 | 0.21 | 0.20 |

Table 10. Continued

| pH Class | Exchangeable | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | K | Ca | Mg | Na | Fe | Mn | H | Al |
| | meq/100 g | | | | | | | |
| > 8.0 | | | | | | | | |
| Range | 0.16-0.48 | 4.45-18.95 | 2.87-7.08 | 0.30-0.98 | 0.013-0.042 | 0.004-0.182 | 0.0-0.0 | 0.06-0.61 |
| Mean | 0.26 | 11.82 | 4.95 | 0.44 | 0.025 | 0.043 | 0.00 | 0.32 |
| SD | 0.08 | 3.79 | 1.39 | 0.16 | 0.01 | 0.04 | 0.00 | 0.14 |

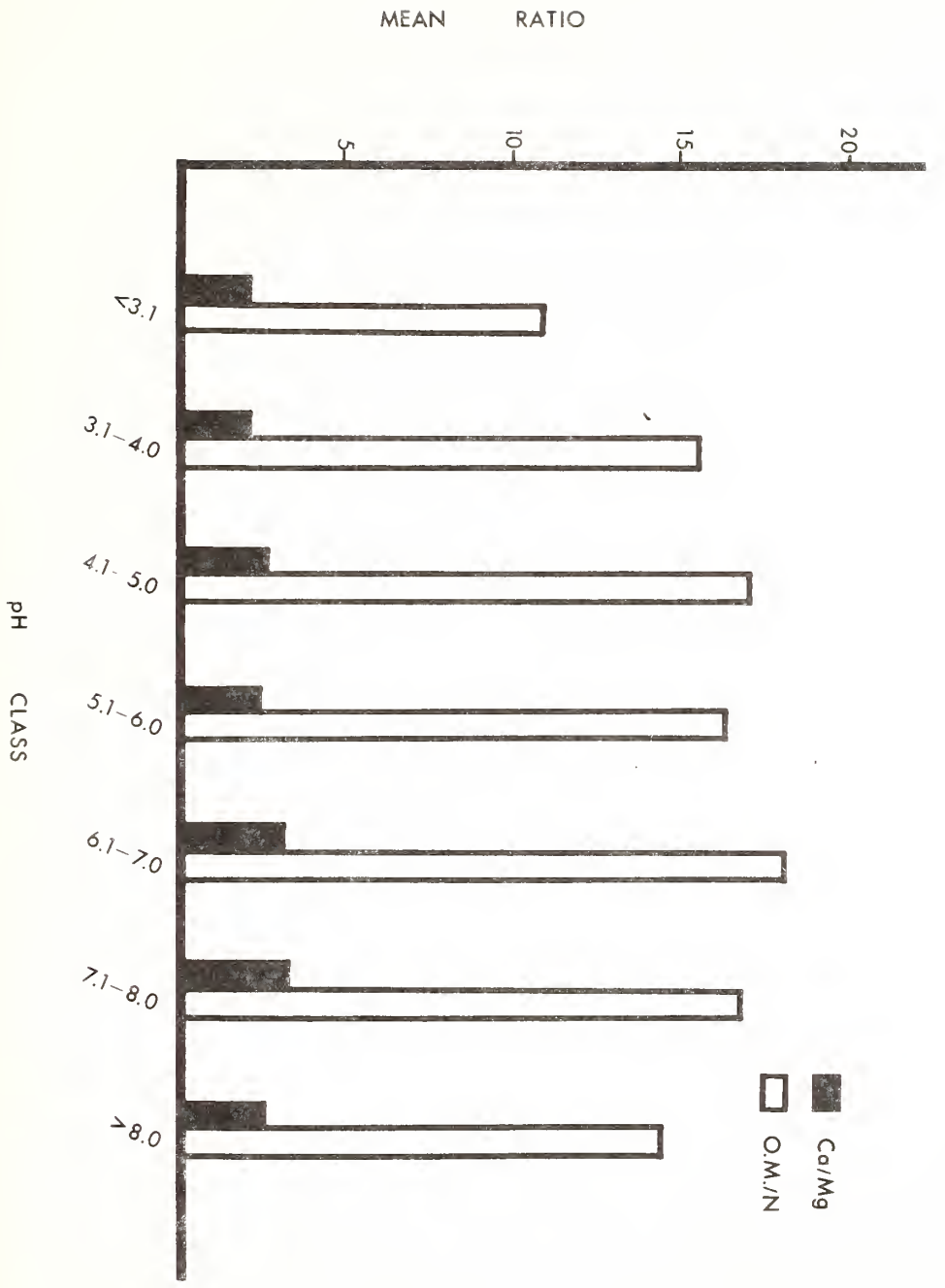


Fig. 8. Average calcium to magnesium and organic matter to nitrogen ratios in spoilbank materials according to pH class.

Total soluble salts (mmhos/cm) and soluble sulfate, manganese, and aluminum was extremely variable in all spoils; but, they tended to show an inverse relationship with pH (Table 11). Below a pH of 4.1, mean amounts of total soluble salts were high and would most likely restrict the yield of all but the most salt-tolerant crops. Within a range of pH from 4.1 to 8.1, average concentrations were such that salt-sensitive crops might be restricted, while the effects of salinity would probably be negligible for those spoils that exhibited a pH greater than 8.0. The possibility of toxic effects to plants due to high concentrations of soluble sulfate, manganese, and aluminum appeared to be greatest in spoils with a pH of less than 5.1 (Tables 5 and 11).

Concentrations of soluble iron were highly variable; but, there was an obvious increase in the average level when pH dropped below 3.1 (Table 11). Below this pH, ferrous and ferric iron were most likely kept in solution, whereas some of the ferric iron probably precipitated as ferric hydroxide when the pH rose above 3.1 (Jackson 1958).

Based upon the results of these analyses, spoil materials that yielded a pH less than 4.1 characteristically possessed properties deleterious to establishment and growth of most vegetation; also, spoils with a pH from 4.1 to 5.1 often showed some adverse properties associated with a low pH. Such properties included high exchangeable acidity and soluble salts; possibly toxic concentrations of soluble sulfate, iron, manganese, and aluminum; and, low base saturations, calcium to magnesium ratios, and organic matter to nitrogen ratios. These results are in general agreement with those of others (Byrnes and Miller 1973; Plass and Vogel 1973; Massey and Barnhisel 1972; Barnhisel and Massey 1969; Beyer and Hutnik 1969;

Table 11. Relationship of pH with levels of soluble salts in spoilbank materials.

| pH | Total Soluble Salts | Soluble | | | |
|---|---|---|---|---|---|
| | | $SO_4$ | Fe | Mn | Al |
| | mmhos/cm | - - - - - - - - - - - - ppm. - - - - - - - - - - - - | | | |
| < 3.1 | | | | | |
| Range | 0.5-8.6 | 12.5-518.8 | 0.6-998.0 | 1.1-16.8 | 3.4-1,920.0 |
| Mean | 2.9 | 287.8 | 208.5 | 5.4 | 525.5 |
| SD | 2.08 | 180.50 | 355.77 | 4.60 | 626.59 |
| 3.1-4.0 | | | | | |
| Range | 0.1-4.9 | 12.5-518.8 | 0.3-450.0 | 1.0-17.9 | 2.5-1,464.0 |
| Mean | 1.6 | 314.2 | 14.3 | 5.3 | 192.9 |
| SD | 1.10 | 143.05 | 56.94 | 4.75 | 273.14 |
| 4.1-5.0 | | | | | |
| Range | 0.0-3.8 | 12.5-465.0 | 0.1-210.0 | 0.8-17.7 | 0.4-480.0 |
| Mean | 0.9 | 210.6 | 6.9 | 5.2 | 13.6 |
| SD | 0.81 | 112.99 | 23.83 | 4.30 | 43.13 |
| 5.1-6.0 | | | | | |
| Range | 0.0-3.5 | 10.0-505.0 | 0.3-250.0 | 0.6-16.6 | 0.4-76.7 |
| Mean | 0.6 | 124.7 | 32.4 | 3.3 | 6.4 |
| SD | 0.72 | 120.17 | 53.18 | 3.02 | 12.87 |
| 6.1-7.0 | | | | | |
| Range | 0.0-3.7 | 0.2-465.0 | 0.1-400.0 | 0.4-17.9 | 0.4-162.0 |
| Mean | 0.8 | 135.1 | 21.3 | 2.1 | 5.6 |
| SD | 0.82 | 119.22 | 47.77 | 1.76 | 25.07 |
| 7.1-8.0 | | | | | |
| Range | 0.0-12.0 | 0.2-425.0 | 0.1-450.0 | 0.2-17.9 | 0.4-43.8 |
| Mean | 0.5 | 76.9 | 6.5 | 1.7 | 2.5 |
| SD | 0.60 | 72.83 | 17.87 | 1.50 | 2.53 |
| > 8.0 | | | | | |
| Range | 0.2-0.5 | 6.3-180.0 | 0.3-7.0 | 0.8-3.0 | 0.4-5.0 |
| Mean | 0.3 | 48.4 | 2.7 | 1.8 | 2.4 |
| SD | 0.09 | 44.87 | 2.28 | 0.80 | 1.14 |

Horn and Ward 1969; Berg and Vogel 1968; Berg 1965; Cummins et al. 1965; Wilson 1965; Struthers 1964; Limstrom 1960; Wilson and Hedrick 1959; Einspahr et al. 1955; and Croxton 1928).

## Spoil Characteristics Associated with Vegetation Density and Age Classes

Although most of the textures in all spoil groups according to vegetation density and age class were loamy, spoils that were poorly vegetated and greater than 2-years-old showed a larger percentage of sandy loam and sandy clay loam (Table 12). No other relationship between texture and vegetation and age classes was apparent.

Only spoils with a vegetation density of less than 25 percent and which were greater than 10-years-old, exhibited an average pH as low as 5.1; however, all vegetation and age classes showed some highly acid samples (Table 13). The occurrence of high acidity in spoils that were less than 11-years-old revealed that acid-forming compounds continued to appear in surface materials after Illinois enacted its first reclamation law (effective 1 January 1962). Haynes and Klimstra (1975) reported that the relative percentages of pre-law and post-law spoils with a pH less than 5.1 were 8 and 7 percent, respectively. This possibly reflects the failure to cover fractured consolidated overburden materials with that from the unconsolidated stratum during the mining operation; or, spoilbank pH may more often reflect the acid-producing potential of unconsolidated strata (Klimstra and Jewell 1974).

It is to be remembered that all spoils less than 3-years-old when sampled were still subject to reclamation requirements stipulated in the Surface-Mined Land Reclamation Act, effective 1 July 1968. Requirements imposed by this law, with the exception of slurry and gob areas where the

Table 12. Relationship of vegetation density and age with texture of Illinois spoilbank materials resulting from surface mining for coal.

| Vegetation Density and Age Classes | Average Texture[a] | No. of Samples | Distribution | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Texture Class[a] | | | | | | | | |
| | | | CL | SC | SL | SCL | Sd | SdCL | SdL | LS | L |
| | | | percent of samples | | | | | | | | |
| < 25%, < 3 yrs. | L | 136 | 4 | 0 | 54 | 2 | 0 | 2 | 7 | 0 | 33 |
| < 25%, 3-10 yrs. | L | 120 | 3 | 0 | 36 | 0 | 0 | 0 | 25 | 0 | 37 |
| < 25%, > 10 yrs. | L | 136 | 3 | 0 | 27 | 0 | 0 | 3 | 21 | 1 | 47 |
| > 25%, < 3 yrs. | L | 39 | 0 | 0 | 44 | 0 | 0 | 0 | 5 | 3 | 49 |
| > 25%, 3-10 yrs. | L | 402 | 4 | 0 | 44 | 1 | 0 | 0 | 10 | 0 | 43 |
| > 25%, > 10 yrs. | L | 1,144 | 3 | < 1 | 34 | 1 | < 1 | < 1 | 14 | < 1 | 47 |
| Percentage, All Samples | | -- | 3 | < 1 | 37 | 1 | < 1 | < 1 | 13 | 1 | 45 |
| Total No. of Samples | | 1,977[b] | 60 | 1 | 734 | 16 | 3 | 8 | 256 | 7 | 891 |

[a]CL = clay loam, SC = silty clay, SL = silt loam, SCL = silt clay loam, Sd = sand, SdCl = sandy clay loam, SdL = sandy loam, LS = loamy sand, L = loam.

[b]Due to insufficient soil, only 1,977 of 2,084 samples were analyzed for texture.

Table 13. Relationship of vegetation density and age with pH of Illinois spoilbank materials resulting from surface mining for coal.

| Vegetation Density and Age Classes | Average pH | Range in pH | No. of Samples | Distribution | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | pH < 3.1 | pH 3.1-4.0 | pH 4.1-5.0 | pH 5.1-6.0 | pH 6.1-7.0 | pH 7.1-8.0 | pH > 8.0 |
| | | | | - - - - - - - - - - - - percent of sample - - - - - - - - - - - - | | | | | | |
| < 25%, < 3 yrs. | 6.4 | 2.5-8.2 | 138 | 1 | 5 | 6 | 6 | 13 | 89 | 2 |
| < 25%, 3-10 yrs. | 6.2 | 2.5-8.0 | 124 | 2 | 11 | 15 | 13 | 16 | 44 | 0 |
| < 25%, > 10 yrs. | 5.1 | 2.1-7.9 | 144 | 7 | 24 | 27 | 14 | 12 | 17 | 0 |
| > 25%, < 3 yrs. | 7.1 | 3.0-8.1 | 42 | 2 | 2 | 7 | 2 | 14 | 64 | 7 |
| > 25%, 3-10 yrs. | 7.2 | 3.3-8.2 | 416 | 0 | 1 | 3 | 6 | 15 | 74 | 1 |
| > 25%, > 10 yrs. | 7.1 | 3.1-8.3 | 1,220 | 0 | 1 | 5 | 7 | 17 | 69 | < 1 |
| Percentage, All Samples | | | -- | 1 | 4 | 7 | 8 | 16 | 65 | 1 |
| Total No. of Samples | | | 2,084 | 15 | 74 | 141 | 158 | 331 | 1,349 | 16 |

chemical or physical conditions of the spoil seemed to justify a delay, were to be accomplished prior to the expiration of 3 years after termination of the permit year (Illinois Department of Conservation 1968).

Seemingly, the data presented in Table 13 suggest that factors other than low pH have resulted in the failure of spoils to become vegetated. Some samples in all vegetation and age categories revealed a pH greater than 5.1, while others from spoils that were adequately vegetated exhibited a pH less than 5.1. However, none of the spoils that were adequately vegetated and were at least 3-years-old showed a pH of less than 3.1. Other factors most likely to prevent or suppress the establishment of vegetation include excessive erosion and stoniness, low fertility and percentage of soil-size particles, and high concentrations of soluble salts. But, as pointed out by Limstrom (1960) the specific effect of any one site factor cannot be isolated or defined due to the combined and interacting effects of all factors.

Amounts of organic matter, nitrogen, and phosphorus according to vegetation and age class were highly variable (Table 14). Average amounts of organic matter and nitrogen were low (Table 5), but spoils that were greater than 10-years-old yielded highest values. Spoils that showed a vegetation density of less than 25 percent tended to show lower mean values; but, average levels of organic matter were about identical in spoils that varied in age from 3 to 11 years. The mean level of nitrogen was slightly higher for poorly vegetated spoils that were less than 3-years-old than in the youngest spoils with adequate vegetation.

Except for spoils that were poorly vegetated and greater than 10-years-old, mean values for phosphorus were low as compared to agricultural standards (Tables 5 and 14). However, Berg (1973) demonstrated that spoils

Table 14. Relationship of vegetation density and age with levels of organic matter, nitrogen, and phosphorus in spoilbank materials.

| Vegetation Density and Age Classes | No. of Samples | O.M. % | N[a] ppm. | pb ppm. |
|---|---|---|---|---|
| < 25%, < 3 yrs. | 138 | | | |
| Range | | 0.0-6.8 | 1.0-3,620.0 | 2.0-47.0 |
| Mean | | 0.99 | 690.51 | 7.96 |
| SD | | 0.94 | 553.00 | 7.73 |
| < 25%, 3-10 yrs. | 124 | | | |
| Range | | 0.0-13.4 | 56.0-4,340.0 | 2.0-93.0 |
| Mean | | 1.43 | 840.38 | 12.57 |
| SD | | 1.45 | 575.82 | 13.76 |
| < 25%, > 10 yrs. | 144 | | | |
| Range | | 0.0-14.5 | 196.0-4,508.0 | 1.0-185.0 |
| Mean | | 1.81 | 992.57 | 19.17 |
| SD | | 2.05 | 657.67 | 24.98 |
| > 25%, < 3 yrs. | 42 | | | |
| Range | | 0.0-7.1 | 252.0-2,191.0 | 2.0-58.0 |
| Mean | | 1.04 | 636.71 | 10.19 |
| SD | | 1.14 | 425.90 | 11.58 |
| > 25%, 3-10 yrs. | 416 | | | |
| Range | | 0.0-13.4 | 79.0-9,828.0 | 2.0-67.0 |
| Mean | | 1.41 | 881.78 | 8.99 |
| SD | | 1.10 | 638.45 | 7.37 |
| > 25%, > 10 yrs. | 1,220 | | | |
| Range | | 0.0-13.7 | 1.0-5,516.0 | 2.0-190.0 |
| Mean | | 1.97 | 1,117.95 | 11.02 |
| SD | | 1.46 | 637.18 | 13.50 |

[a]Total nitrogen.

[b]Bray #1.

from southern Appalachian coal fields yielding over 8 ppm. phosphorus showed adequate amounts for herbaceous ground cover. Values less than 4 ppm. were usually considered deficient, whereas plant growth was variable when levels ranged from 4 to 8 ppm. Based on these indexes, none of the mean values for Illinois spoils (Table 14) were deficient.

Average levels of phosphorus were somewhat higher in spoils that were poorly vegetated and which ranged in age from 3 to more than 10 years. Probably the use of acid ammonium fluoride as an extractant resulted in the determination of larger amounts in these spoils, because they also exhibited the greatest percentage of samples with a pH of less than 6.1 (Tables 13 and 14 and p. 41).

Mean cation exchange capacities for all vegetation and age groups were within the range reported for most soils in the Midwest (Fig. 9 and Table 5). Spoils showing a vegetation density of less than 25 percent and which were over 10-years-old exhibited the largest mean cation exchange capacity; this reflected the higher amounts of exchangeable acidity (hydrogen and aluminum) in these spoils (Fig. 9 and Table 15). All poorly vegetated spoils showed lower mean base saturations and therefore, higher exchangeable acidities.

Average amounts of exchangeable potassium were low in all spoils except those adequately vegetated and varied in age from 3 to over 10 years. Mean exchangeable calcium was low in spoils poorly vegetated; but, it was adequate in other spoils. Average amounts of magnesium and sodium were adequate. Levels of exchangeable iron were highly variable ranging from 0.0 to 2.04 meq/100 g of spoil; no relationship between exchangeable iron and vegetation and age groups was evidenced. As a group, average levels of exchangeable manganese were higher in poorly vegetated spoils (Tables 15 and 5 and Fig. 9).

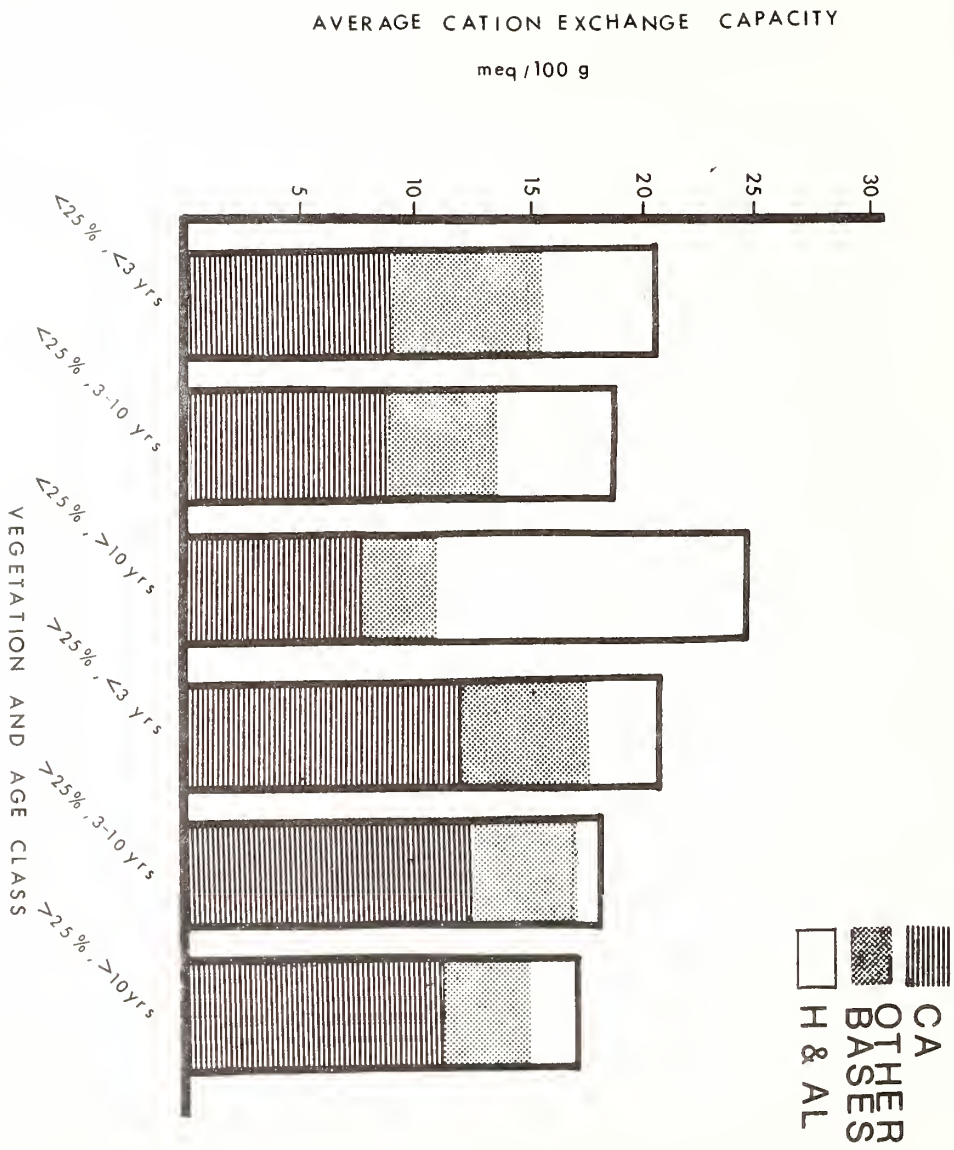


Fig. 9. Relationship between average percentage base saturation, exchangeable calcium and other bases, and mean cation exchange capacity according to vegetation density and age classes of spoilbank materials.

Table 15. Relationship of vegetation density and age with levels of exchangeable cations in spoilbank materials.

| Vegetation Density and Age Classes | Exchangeable | | | |
|---|---|---|---|---|
| | K | Ca | Mg | Na |
| | meq/100 g | | | |
| < 25%, < 3 yrs. | | | | |
| Range | 0.11-0.37 | 0.25-14.03 | 0.25-14.33 | 0.30-1.26 |
| Mean | 0.24 | 8.67 | 5.15 | 0.48 |
| SD | 0.06 | 4.16 | 2.37 | 0.18 |
| < 25%, 3-10 yrs. | | | | |
| Range | 0.06-0.51 | 0.35-21.80 | 0.33-8.96 | 0.15-1.15 |
| Mean | 0.27 | 8.59 | 3.98 | 0.43 |
| SD | 0.08 | 5.24 | 1.98 | 0.16 |
| < 25%, > 10 yrs. | | | | |
| Range | 0.03-0.69 | 0.09-62.00 | 0.29-8.96 | 0.20-1.13 |
| Mean | 0.23 | 6.99 | 2.93 | 0.38 |
| SD | 0.11 | 7.59 | 1.87 | 0.10 |
| > 25%, < 3 yrs. | | | | |
| Range | 0.04-0.57 | 4.25-21.20 | 0.52-13.42 | 0.33-1.15 |
| Mean | 0.28 | 11.63 | 5.12 | 0.52 |
| SD | 0.10 | 4.04 | 2.55 | 0.16 |
| > 25%, 3-10 yrs. | | | | |
| Range | 0.13-1.49 | 3.45-25.00 | 1.02-13.88 | 0.22-1.30 |
| Mean | 0.34 | 11.66 | 4.45 | 0.45 |
| SD | 0.11 | 3.66 | 1.70 | 0.15 |
| > 25%, > 10 yrs. | | | | |
| Range | 0.03-2.08 | 0.58-45.75 | 0.23-9.79 | 0.16-1.15 |
| Mean | 0.35 | 10.55 | 3.76 | 0.41 |
| SD | 0.12 | 4.54 | 1.59 | 0.09 |

Table 15. Continued

| Vegetation Density and Age Classes | Exchangeable | | | |
|---|---|---|---|---|
| | Fe | Mn | H | Al |
| | meq/100 g | | | |
| < 25%, < 3 yrs. | | | | |
| Range | 0.00-1.21 | 0.00-0.95 | 0.0-27.0 | 0.06-14.46 |
| Mean | 0.05 | 0.14 | 3.66 | 1.74 |
| SD | 0.18 | 0.23 | 6.87 | 3.23 |
| < 25%, 3-10 yrs. | | | | |
| Range | 0.00-0.06 | 0.00-0.89 | 0.0-27.0 | 0.03-9.79 |
| Mean | 0.02 | 0.09 | 4.13 | 1.21 |
| SD | 0.01 | 0.12 | 6.90 | 1.75 |
| < 25%, > 10 yrs. | | | | |
| Range | 0.00-2.04 | 0.00-0.73 | 0.0-40.0 | 0.00-23.36 |
| Mean | 0.04 | 0.13 | 10.36 | 3.43 |
| SD | 0.18 | 0.13 | 9.65 | 4.24 |
| > 25%, < 3 yrs. | | | | |
| Range | 0.00-1.61 | 0.00-0.68 | 0.0-28.0 | 0.06-7.34 |
| Mean | 0.06 | 0.08 | 2.11 | 0.75 |
| SD | 0.25 | 0.11 | 6.11 | 1.28 |
| > 25%, 3-10 yrs. | | | | |
| Range | 0.00-0.08 | 0.00-0.83 | 0.0-22.0 | 0.00-5.33 |
| Mean | 0.02 | 0.06 | 0.72 | 0.44 |
| SD | 0.01 | 0.08 | 2.86 | 0.59 |
| > 25%, > 10 yrs. | | | | |
| Range | 0.00-1.39 | 0.00-0.91 | 0.0-27.0 | 0.00-14.00 |
| Mean | 0.02 | 0.06 | 1.20 | 0.60 |
| SD | 0.08 | 0.08 | 3.91 | 1.12 |

Average calcium to magnesium ratios were low in all vegetation and age groups; but, they were lowest in spoils with a vegetation density of less than 25 percent. Spoils adequately vegetated and older than 10 years showed the highest mean ratios of calcium to magnesium and organic matter to nitrogen. Only these spoils exhibited an organic matter to nitrogen ratio as large as 20:1, which commonly occurs in most surface soils in the United States (Fig. 10 and Table 5).

All vegetation and age groups, except those with a vegetation density of more than 25 percent and which varied in age from 3 to over 10 years, exhibited average concentrations of total soluble salts (mmhos/cm) high enough to limit the yield of most crops. The highest concentration occurred in the poorly vegetated spoils greater than 10-years-old (Tables 16 and 5). Mean concentrations of soluble sulfate, manganese, and aluminum were higher in all groups exhibiting a vegetation density of less than 25 percent. Those greater than 10-years-old revealed the highest average concentrations. Levels of soluble iron were highly variable between groups and no relationship could be determined.

In summary, some of the spoils in all vegetation and age classes showed properties that are generally considered deleterious to the growth of many species of plants. But, spoils with a vegetation density of less than 25 percent most often exhibited adverse properties such as low pH, low fertility, high exchangeable acidity, and high concentrations of soluble salts. The most adverse conditions usually occurred in the poorly vegetated spoils over 10-years-old.

The distribution of samples in each vegetation and age class according to whether or not leguminous plants were present, the degree of grading, and the type of utilization are presented in Tables 17 and 18. Legumes

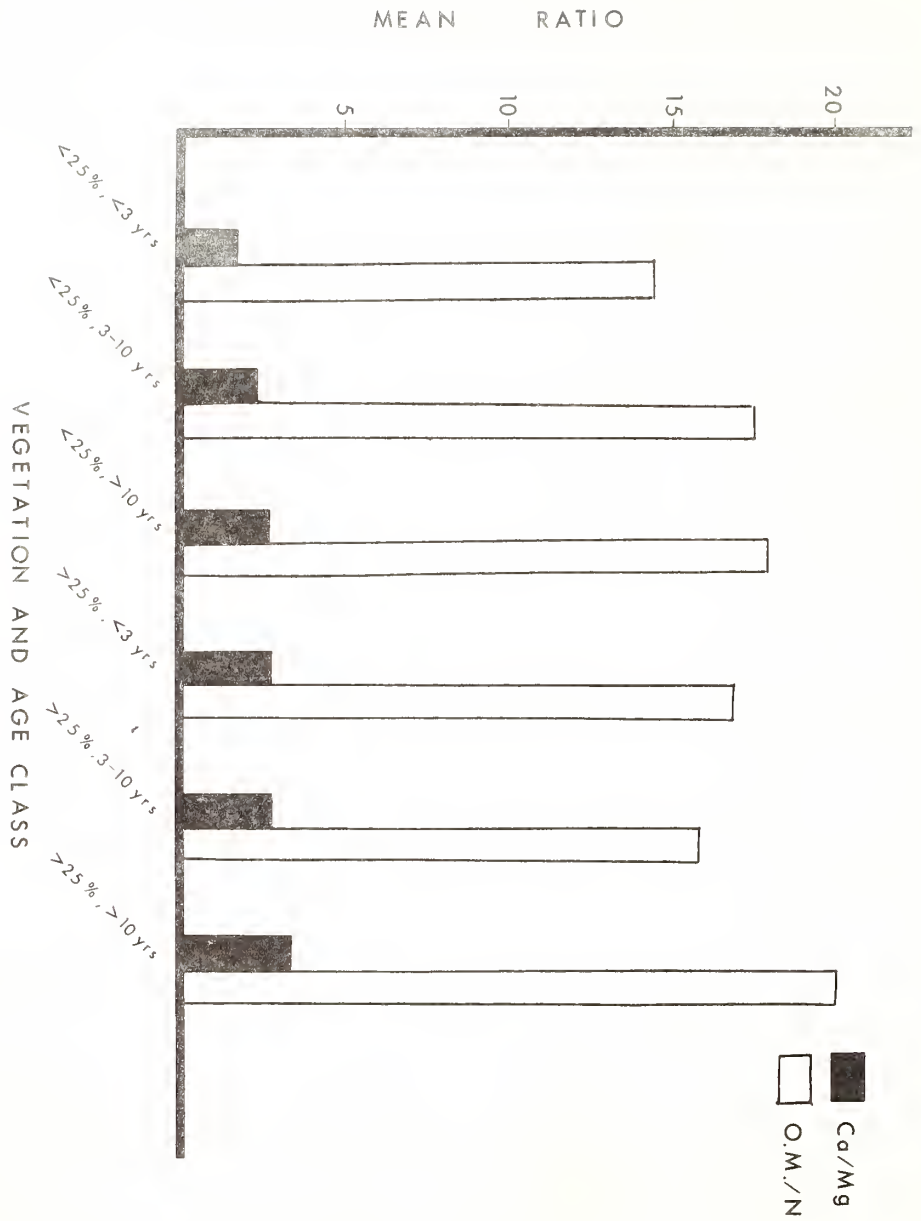


Fig. 10. Average calcium to magnesium and organic matter to nitrogen ratios in spoilbank materials according to vegetation density and age class.

Table 16. Relationship of vegetation density and age with levels of soluble salts in spoilbank materials.

| Vegetation Density and Age Classes | Total Soluble Salts | Soluble | | | |
|---|---|---|---|---|---|
| | | $SO_4$ | Fe | Mn | Al |
| | mmhos/cm | - - - - - - - - - - ppm. - - - - - - - - - - | | | |
| < 25%, < 3 yrs. | | | | | |
| Range | 0.1-3.4 | 17.8-505.0 | 0.3-450.0 | 0.6-16.1 | 0.4-600.0 |
| Mean | 0.88 | 170.59 | 13.42 | 2.96 | 34.87 |
| SD | 0.95 | 140.85 | 66.84 | 3.39 | 114.95 |
| < 25%, 3-10 yrs. | | | | | |
| Range | 0.0-12.0 | 11.3-518.8 | 0.3-170.0 | 0.2-14.9 | 0.4-1,120.0 |
| Mean | 0.97 | 166.83 | 8.37 | 2.78 | 31.72 |
| SD | 1.29 | 125.92 | 24.68 | 2.45 | 122.93 |
| < 25%, > 10 yrs. | | | | | |
| Range | 0.0-8.6 | 8.8-518.8 | 0.3-996.0 | 0.8-17.9 | 0.4-1,920.0 |
| Mean | 1.12 | 209.19 | 20.08 | 4.16 | 85.83 |
| SD | 1.18 | 142.50 | 89.50 | 4.21 | 258.23 |
| > 25%, < 3 yrs. | | | | | |
| Range | 0.1-3.8 | 11.3-505.0 | 0.4-998.0 | 0.8-10.3 | 0.8-492.0 |
| Mean | 0.89 | 132.90 | 28.17 | 1.83 | 22.77 |
| SD | 0.95 | 105.59 | 153.54 | 1.45 | 87.65 |
| > 25%, 3-10 yrs. | | | | | |
| Range | 0.0-3.4 | 0.2-465.0 | 0.1-310.0 | 0.2-14.9 | 0.4-936.0 |
| Mean | 0.66 | 104.81 | 8.11 | 1.95 | 5.72 |
| SD | 0.65 | 97.70 | 28.75 | 1.93 | 49.17 |
| > 25%, > 10 yrs. | | | | | |
| Range | 0.1-5.4 | 0.2-518.8 | 0.1-450.0 | 0.2-17.9 | 0.4-2,976.0 |
| Mean | 0.49 | 86.84 | 13.22 | 2.12 | 9.43 |
| SD | 0.57 | 92.69 | 32.90 | 2.32 | 100.00 |

Table 17. Relationship of vegetation density and age with legumes and degree of grading of spoilbanks.

| Vegetation Density and Age Classes | No. of Samples | Legumes | | Degree of Grading | | |
|---|---|---|---|---|---|---|
| | | Present | Absent | None | Strike Off | Rolling or Level |
| | | - - - - - - - - - - - - - - percent of samples - - - - - - - - - - - - - - | | | | |
| < 25%, < 3 yrs. | 138 | 14 | 86 | 36 | 23 | 42 |
| < 25%, 3-10 yrs. | 124 | 6 | 94 | 53 | 36 | 11 |
| < 25%, > 10 yrs. | 144 | 1 | 99 | 84 | 8 | 8 |
| > 25%, < 3 yrs. | 42 | 71 | 29 | 17 | 48 | 36 |
| > 25%, 3-10 yrs. | 416 | 54 | 46 | 20 | 40 | 40 |
| > 25%, > 10 yrs. | 1,220 | 17 | 83 | 60 | 15 | 25 |
| Percentage, All Samples | -- | 24 | 76 | 51 | 22 | 27 |
| Total No. of Samples | 2,084 | 491 | 1,592 | 1,056 | 459 | 569 |

Table 18. Relationship of vegetation density and age with utilization of coal surface-mined lands.

| Vegetation Density and Age Classes | No. of Samples | Utilization | | | | | |
|---|---|---|---|---|---|---|---|
| | | None Observed | Active Mine | Pasture or Hay | Other Crops | Recreation | Other |
| | | percent of samples | | | | | |
| < 25%, < 3 yrs. | 138 | 62 | 17 | 2 | 18 | 0 | 1 |
| < 25%, 3-10 yrs. | 124 | 93 | 0 | 7 | 0 | 0 | 0 |
| < 25%, > 10 yrs. | 144 | 84 | 0 | 11 | 0 | 5 | 1 |
| > 25%, < 3 yrs. | 42 | 55 | 0 | 43 | 2 | 0 | 0 |
| > 25%, 3-10 yrs. | 416 | 51 | 1 | 45 | 1 | 2 | 0 |
| > 25%, > 10 yrs. | 1,220 | 41 | 0 | 42 | 0 | 15 | 2 |
| Percentage, All Samples | -- | 51 | 1 | 36 | 2 | 9 | 1 |
| Total No. of Samples | 2,084 | 1,052 | 28 | 749 | 35 | 194 | 26 |

were most often observed on adequately vegetated spoils; but, they were recorded on only 24 percent of the sample sites. Average levels of organic matter and nitrogen also tended to be greater in these spoils, but the relationship was obscured (Tables 14 and 17). Although legumes were present on 1 percent of the sample sites that were poorly vegetated and over 10-years-old, the average amount of organic matter and nitrogen was comparatively high. Seemingly, age of the spoils had a strong influence on the amounts of organic matter and nitrogen.

Although 51 percent of the sample sites had not been graded, spoils over 10-years-old and those poorly vegetated, showed the largest percentage of sites not graded. Evidenced is the influence of the first operational reclamation law, which became effective on 1 January 1962. Haynes and Klimstra (1975) noted that 39 percent of the pre-law and 75 percent of the post-law spoils (33,999 and 42,512 acres, respectively) had been subjected to grading as of 30 June 1971.

As expected, the observed utilization of mined lands was greatest on sample sites that were adequately vegetated (Table 18). Pasture, hay, and recreational areas accounted for most of the use; recreational areas were most common on the oldest spoils. As of 30 June 1971, 46,387 acres were estimated to have been used for pasture, 3,851 acres for the production of hay, and 27,777 acres for recreation; no utilization was noted on 51 percent of the sample sites or 76,653 acres (Haynes and Klimstra 1975).

The extent of coal surface-mined lands in Illinois that exhibited a vegetation density of less than 25 percent as of 30 June 1971 was estimated by Haynes and Klimstra (1975) at 9,799 acres or 6.8 percent of all spoilbanks. Specific descriptions of these and other problem sites have been documented by Klimstra and Terpening (1974). About 4,505 acres revealed a

pH greater than 5.1 and a vegetation density of less than 25 percent. Areas with a pH less than 5.1 and vegetation density less than 25 percent yielded 5,294 acres.

Total acreages per region varied from 76 in Region I to 4,685 in Region IV (Fig. 11). Spoilbanks poorly vegetated and yielding a low pH were recorded primarily in Grundy and LaSalle counties (Region II), Schuyler County (Region III), Saline and Williamson counties (Region IV), and Jackson County (Region V). Will, Vermilion, and Perry counties (Regions II, III, and V, respectively) yielded large acreages that were poorly vegetated but had a pH greater than 5.1 (Haynes and Klimstra 1975). Although the chemical properties of spoilbank materials were highly variable within counties and regions, some spoilbanks in all counties and regions exhibited chemical properties deleterious to plant growth. However, spoilbank materials from those counties and regions which showed the largest acreages that were poorly vegetated usually revealed a lower pH; higher concentrations of soluble aluminum, manganese, and other salts; lower fertility; and, higher exchangeable acidity (Appendix, Tables D-F). Also, factors such as excessive erosion and stoniness, low percentage of soil-size particles, and other unidentified factors must have resulted in the absence of vegetation on some spoilbanks, especially those in Will, Vermilion, and Perry counties.

### Some Chemical Properties of Coal Refuse

Coal refuse consists of waste coal, slate, shale, clay, and other materials separated from the coal during the cleaning and preparation process. Slurry contains the fine reject materials of less than 20 mesh that can be pumped into slurry lagoons or other impoundments where the suspended solids settle. Gob is composed of the coarser materials that cannot be pumped and

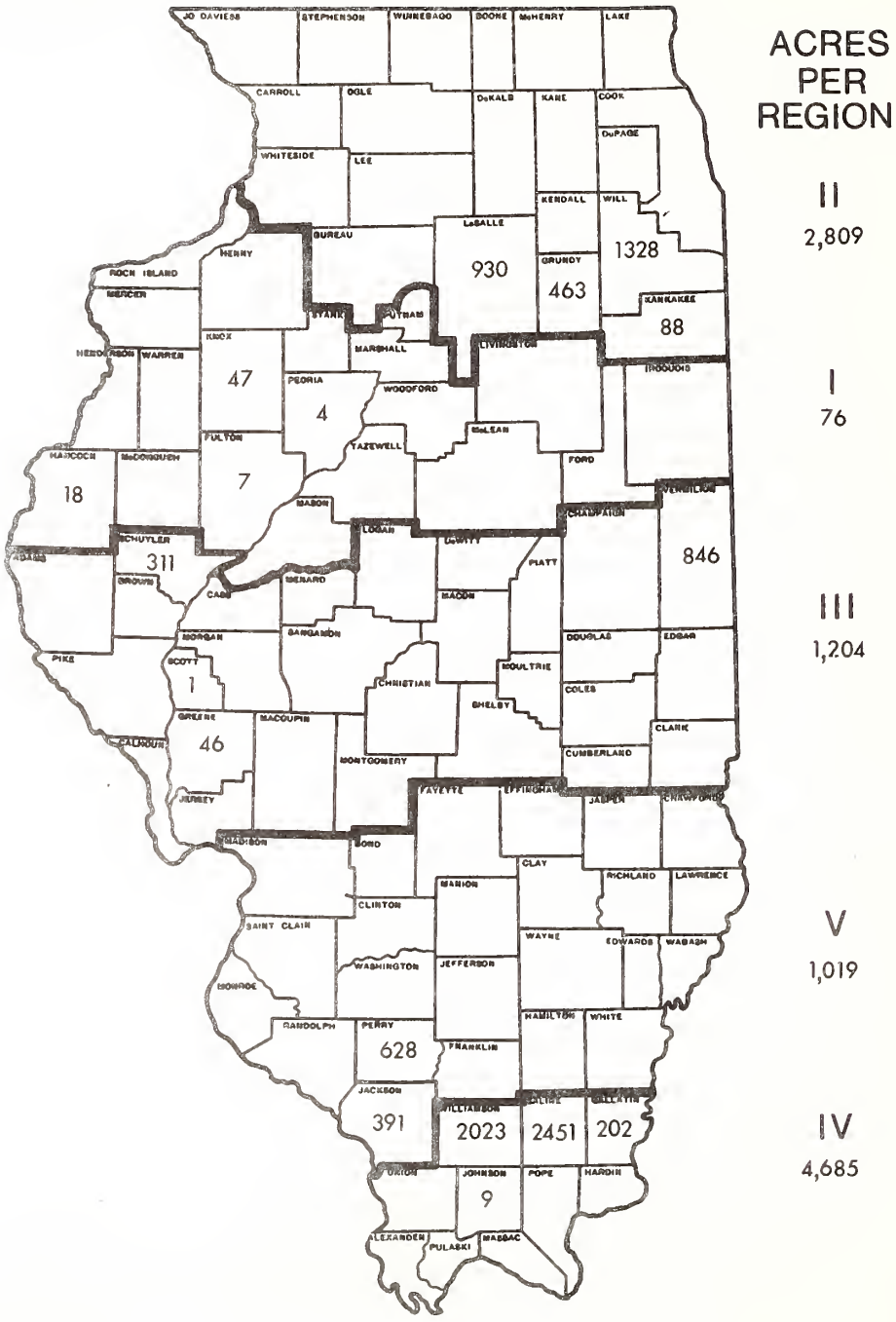


Fig. 11. Acreage of spoilbanks with an estimated vegetation density of less than 25 percent, according to County and Region as of 30 June 1971 (from Haynes and Klimstra 1975, Appendix H, Table Z).

which are usually carried by truck to a disposal site. Both slurry and gob commonly contain large amounts of acid-forming materials (mostly pyrite), which upon oxidation yield high concentrations of sulfuric acid and associated toxic ions in solution (Ramsey 1974; United States Department of the Interior 1973).

During this investigation, 17 samples of solid slurry material and 5 of gob were collected from different refuse areas in Illinois and analyzed for selected chemical properties (Appendix, Table B). Most of the slurry samples exhibited a pH less than 4.0, whereas all of the gob samples revealed a pH less than 3.1 (Tables 19 and 20). Two slurry samples which showed pH's of 7.4 and 7.0 represented samples collected from slurry less than 2-years-old and a vegetated portion of an otherwise barren site. Nielson and Peterson (1972) studying the properties of copper tailings which were basic when discharged, reported that areas nearest to the discharge pipe yielded the greatest accumulation of pyrites and became acidified first; slimes at the far end of the pond were the slowest to acidify. Similar properties for coal slurry could account for the relatively high pH values shown in our studies (Table 19).

Levels of available phosphorus were highly variable, ranging from 2 to 170 ppm. in slurry and from 5 to 20 ppm. in gob (Tables 19 and 20). Although median values were similar for slurry and gob, the value for slurry was considerably larger. Based on agricultural standards (Table 5), 71 percent of the slurry and all but one of the gob samples exhibited low levels of available phosphorus.

Both slurry and gob yielded high concentrations of soluble salts (Tables 19 and 20). Values ranged from 0.3 to 5.3 (mmhos/cm); with most greater than 1.5, which restricts crop yields (Table 5). Concentrations

Table 19. Levels of pH, available phosphorus, and soluble salts in slurry refuse associated with surface mining for coal in Illinois.

| Sample No.[a] | pH | P[b] | Total Soluble Salts | Soluble | | | |
|---|---|---|---|---|---|---|---|
| | | | | $SO_4$ | Fe | Mn | Al |
| | | | mmhos/cm | ppm. | | | |
| 38 | 2.9 | 10 | 2.4 | 260.0 | 100.0 | 5.5 | 93.6 |
| 146 | 3.1 | 3 | 0.8 | 166.3 | 6.6 | 6.6 | 14.7 |
| 191 | 2.5 | 15 | 3.8 | 505.0 | 500.0 | 14.6 | 480.0 |
| 260 | 5.1 | 6 | 1.8 | 505.0 | 0.9 | 10.9 | 1.7 |
| 280 | 2.2 | 7 | 5.2 | 518.8 | 400.0 | 15.3 | 360.0 |
| 300 | 2.3 | 170 | 4.0 | 518.8 | 600.0 | 14.4 | 649.0 |
| 439 | 3.0 | 9 | 2.2 | 505.0 | 2.5 | 17.2 | 25.8 |
| 616 | 7.4 | 4 | 2.4 | 287.5 | 3.6 | 2.0 | 2.5 |
| 1,020 | 3.8 | 22 | 2.7 | 287.5 | 19.7 | 0.8 | 201.6 |
| 1,038 | 2.8 | 2 | 3.2 | 174.5 | 150.0 | 6.8 | 129.6 |
| 1,061 | 4.3 | 14 | 2.3 | 260.0 | 5.2 | 1.7 | 25.8 |
| 1,262 | 3.6 | 10 | 0.3 | 152.5 | 2.8 | 1.0 | 6.7 |

Table 19. Continued

| Sample No.[a] | pH | P[b] | Total Soluble Salts | Soluble | | | |
|---|---|---|---|---|---|---|---|
| | | | | $SO_4$ | Fe | Mn | Al |
| | | | mmhos/cm | ppm. | | | |
| 1,797 | 7.0 | 4 | 2.1 | 425.0 | 2.5 | 3.0 | 0.6 |
| 1,833 | 3.8 | 11 | 0.4 | 133.3 | 3.2 | 1.5 | 7.1 |
| 2,003 | 2.9 | 6 | 3.1 | 397.5 | 380.0 | 2.0 | 288.0 |
| 2,063 | 2.8 | 17 | 3.9 | 518.8 | 994.0 | 4.4 | 162.0 |
| 2,508 | 2.9 | 68 | 4.2 | 425.0 | 997.0 | 6.4 | 288.0 |
| Range | 2.2-7.4 | 2-170 | 0.3-5.2 | 133.3-518.8 | 0.9-997.0 | 0.8-17.2 | 0.6-649.0 |
| Median | 3.0 | 10 | 2.4 | 397.5 | 19.7 | 5.5 | 93.6 |
| Mean | 3.7 | 22 | 2.6 | 355.3 | 245.2 | 6.7 | 161.0 |
| SD | 1.52 | 40.99 | 1.36 | 146.86 | 345.29 | 5.63 | 193.75 |

[a]See Appendix, Table B for location and description of samples.

[b]Bray #1.

Table 20. Levels of pH, available phosphorus, and soluble salts in gob refuse associated with surface mining for coal in Illinois.

| Sample No.[a] | pH | P[b] | Total Soluble Salts | Soluble | | | |
|---|---|---|---|---|---|---|---|
| | | | | $SO_4$ | Fe | Mn | Al |
| | | | mmhos/cm | ppm. | | | |
| 298 | 2.6 | 9 | 3.0 | 485.0 | 8.2 | 2.1 | 201.6 |
| 731 | 2.9 | 19 | 0.3 | 219.3 | 44.0 | 8.8 | 201.6 |
| 1,045 | 2.4 | 12 | 0.7 | 315.0 | 997.0 | 16.3 | 492.0 |
| 1,523 | 2.9 | 5 | 1.9 | 370.0 | 20.0 | 2.7 | 64.1 |
| 1,980 | 3.0 | 13 | 1.7 | 287.5 | 50.0 | 2.5 | 93.6 |
| Range | 2.4-3.0 | 5-19 | 0.3-3.0 | 219.3-485.0 | 8.2-997.0 | 2.1-16.3 | 64.1-492.0 |
| Median | 2.9 | 12 | 1.7 | 315.0 | 44.0 | 2.7 | 201.6 |
| Mean | 2.8 | 12 | 1.5 | 335.4 | 223.8 | 6.5 | 210.6 |
| SD | 0.25 | 5.20 | 1.06 | 99.71 | 432.55 | 6.15 | 169.19 |

[a]See Appendix, Table B for location and description of samples.

[b]Bray #1.

of soluble sulfate, iron, manganese, and aluminum were extremely variable. Soluble iron showed significant increase when the pH fell below 3.0; this probably reflected the combined solubility of ferrous and ferric ions under extreme acid conditions. Above 3.0, the ferric ion probably precipitated as ferric hydroxide (Jackson 1958). Correlations between levels of soluble salts and toxicity to plants have not been established; but, because most slurries and all gob areas were barren (Appendix, Table B), most values observed should be considered toxic.

Approximately 46 percent of gob and slurry samples exhibited a cation exchange capacity considerably larger than that commonly found in the surface horizon of most soils in the Midwest (Fig. 12 and Table 5). This was due in part to high reserve acidities (exchangeable hydrogen and aluminum); however, some samples yielded exceptionally high amounts of exchangeable calcium, even when the pH was extremely low (Tables 21 and 22). These high calcium-low pH samples were rechecked by Nu-Ag Laboratories and verified. As discussed by Heald (1965:1,000-1,001), interference from high concentrations of soluble salts may have caused inaccurate determinations of exchangeable calcium.

Even though amounts of exchangeable calcium were high, most samples revealed base saturations that were low (Fig. 12 and Tables 21, 22, and 5). Except for two slurry samples that were non-acid, all samples exhibited a base saturation of less than 60 percent. Exchangeable potassium was very low in about 91 percent of the samples, while all values for magnesium and sodium were probably adequate for plant growth. Although most samples had rather high amounts of exchangeable magnesium, the levels of calcium often observed resulted in some very high calcium to magnesium ratios (Fig. 13); 36 percent revealed ratios greater than 26:1, whereas only 14 percent (3

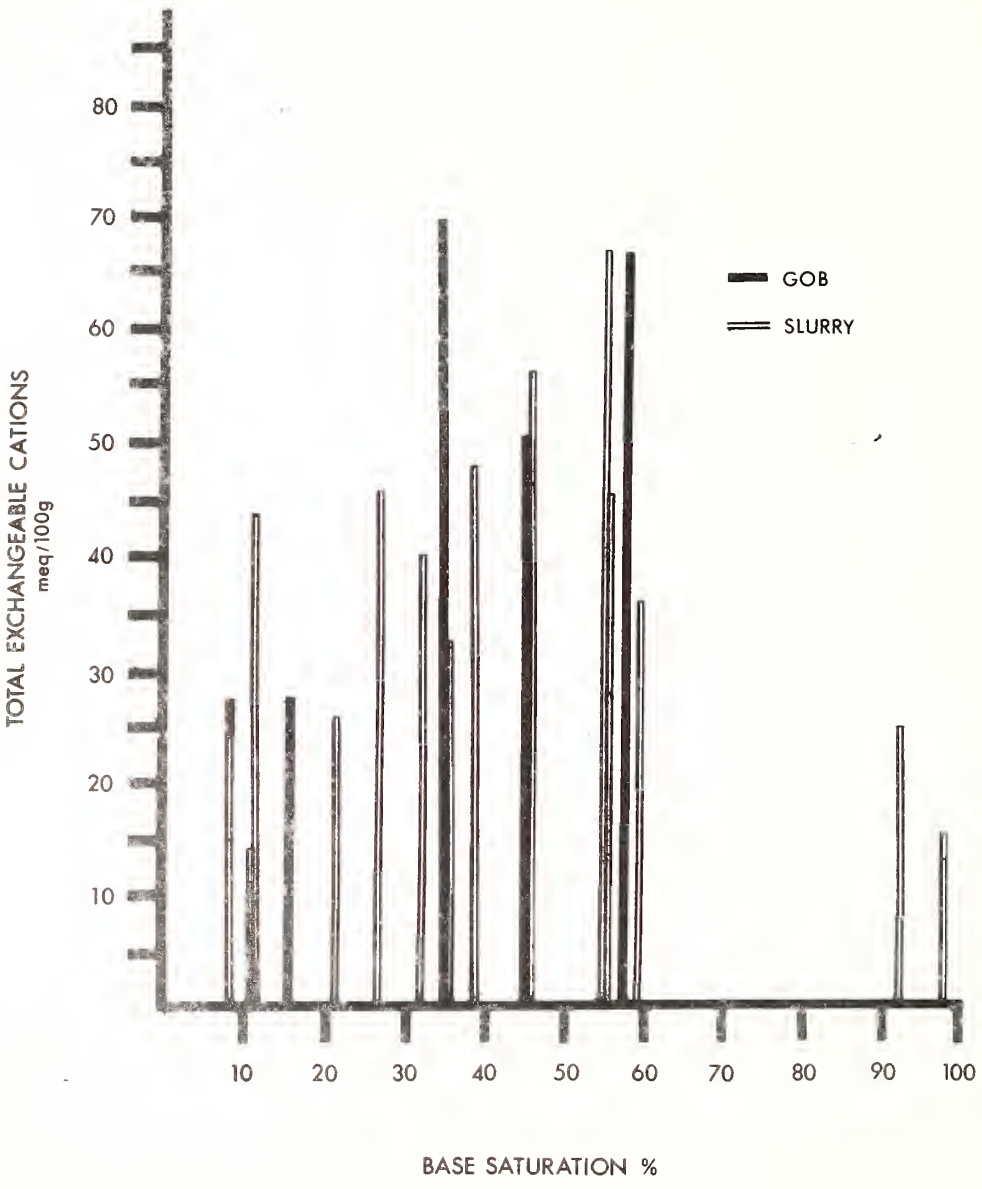


Fig. 12. Percentage base saturation and total exchangeable cations in slurry and gob refuse associated with surface mining for coal in Illinois.

Table 21. Levels of exchangeable cations in slurry refuse associated with surface mining for coal in Illinois.

| Sample No.[a] | Exchangeable | | | | | | | | % Base Sat. |
|---|---|---|---|---|---|---|---|---|---|
| | K | Ca | Mg | Na | Fe | Mn | H | Al | |
| | meq/100 g | | | | | | | | |
| 38 | 0.09 | 17.55 | 0.67 | 0.54 | 0.020 | 0.015 | 26.0 | 3.50 | 39 |
| 146 | 0.03 | 0.45 | 0.31 | 0.41 | 0.027 | 0.015 | 8.0 | 0.61 | 12 |
| 191 | 0.03 | 0.35 | 0.63 | 0.26 | 4.296 | 0.045 | 37.0 | 2.05 | 12 |
| 260 | 0.19 | 23.00 | 0.84 | 0.54 | 0.037 | 0.127 | 1.4 | 0.55 | 92 |
| 280 | 0.06 | 35.00 | 0.59 | 0.50 | 0.537 | 0.055 | 29.0 | 1.33 | 54 |
| 300 | 0.04 | 4.65 | 1.85 | 0.37 | 5.371 | 0.114 | 29.0 | 3.89 | 27 |
| 439 | 0.11 | 23.90 | 0.89 | 0.50 | 0.042 | 0.087 | 19.0 | 1.39 | 55 |
| 616 | 0.23 | 12.10 | 3.13 | 1.07 | 0.042 | 0.073 | 0.0 | 0.22 | 98 |
| 1,020 | 0.03 | 10.00 | 1.43 | 0.43 | 0.012 | 0.396 | 18.0 | 3.61 | 36 |
| 1,038 | 0.03 | 1.38 | 0.31 | 0.26 | 0.011 | 0.015 | 20.0 | 2.28 | 8 |
| 1,061 | 0.13 | 8.00 | 13.42 | 0.61 | 0.013 | 0.004 | 14.0 | 1.39 | 59 |
| 1,262 | 0.07 | 0.75 | 0.44 | 0.37 | 0.007 | 0.004 | 11.4 | 1.33 | 11 |
| 1,797 | 0.33 | 10.00 | 3.61 | 1.28 | 0.004 | 0.080 | 0.0 | 0.22 | 98 |

Table 21. Continued

| Sample No.[a] | Exchangeable K | Ca | Mg | Na | Fe | Mn | H | Al | % Base Sat. |
|---|---|---|---|---|---|---|---|---|---|
| | meq/100 g | | | | | | | | |
| 1,833 | 0.06 | 0.75 | 0.23 | 0.30 | 0.021 | 0.004 | 14.0 | 0.50 | 8 |
| 2,003 | 0.03 | 1.75 | 1.95 | 0.39 | 1.074 | 0.309 | 17.0 | 3.55 | 21 |
| 2,063 | 0.04 | 25.00 | 0.52 | 0.61 | 0.010 | 0.032 | 28.0 | 1.72 | 46 |
| 2,508 | 0.03 | 7.50 | 1.38 | 0.37 | 3.652 | 0.109 | 23.0 | 4.16 | 32 |
| Range | 0.03-0.33 | 0.35-35.00 | 0.23-13.42 | 0.26-1.28 | 0.004-5.370 | 0.004-0.396 | 0.0-37.0 | 0.22-3.89 | 8-98 |
| Median | 0.06 | 8.00 | 0.84 | 0.43 | 0.027 | 0.055 | 18.0 | 1.72 | 36 |
| Mean | 0.09 | 10.71 | 1.89 | 0.52 | 0.892 | 0.087 | 17.3 | 1.90 | 42 |
| SD | 0.09 | 10.61 | 3.13 | 0.27 | 1.74 | 0.44 | 8.95 | 1.36 | 31 |

[a]See Appendix, Table B for location and description of samples.

Table 22. Levels of exchangeable cations in gob refuse associated with surface mining for coal in Illinois.

| Sample No.[a] | Exchangeable | | | | | | | | % Base Sat. |
|---|---|---|---|---|---|---|---|---|---|
| | K | Ca | Mg | Na | Fe | Mn | H | Al | |
| | meq/100 g | | | | | | | | |
| 298 | 0.33 | 22.25 | 0.27 | 0.63 | 0.04 | 0.01 | 26.0 | 2.22 | 45 |
| 731 | 0.06 | 37.50 | 1.02 | 0.63 | 0.02 | 0.04 | 26.0 | 2.72 | 57 |
| 1,045 | 0.03 | 18.25 | 0.59 | 0.50 | 5.26 | 0.08 | 41.0 | 4.11 | 35 |
| 1,523 | 0.03 | 2.50 | 1.38 | 0.35 | 0.01 | 0.01 | 22.0 | 1.77 | 15 |
| 1,980 | 0.07 | 1.20 | 0.73 | 0.35 | 0.02 | 0.01 | 22.0 | 3.00 | 8 |
| Range | 0.03-0.33 | 1.20-37.50 | 0.27-1.38 | 0.35-0.63 | 0.01-5.26 | 0.01-0.08 | 22.0-41.0 | 1.77-4.11 | 8-57 |
| Median | 0.06 | 18.25 | 0.73 | 0.50 | 0.02 | 0.01 | 26.0 | 2.72 | 35 |
| Mean | 0.10 | 16.34 | 0.80 | 0.49 | 1.07 | 0.03 | 27.4 | 2.76 | 32 |
| SD | 0.15 | 15.06 | 0.42 | 0.14 | 2.34 | 0.03 | 7.86 | 0.89 | 20 |

[a]See Appendix, Table B for location and description of samples.

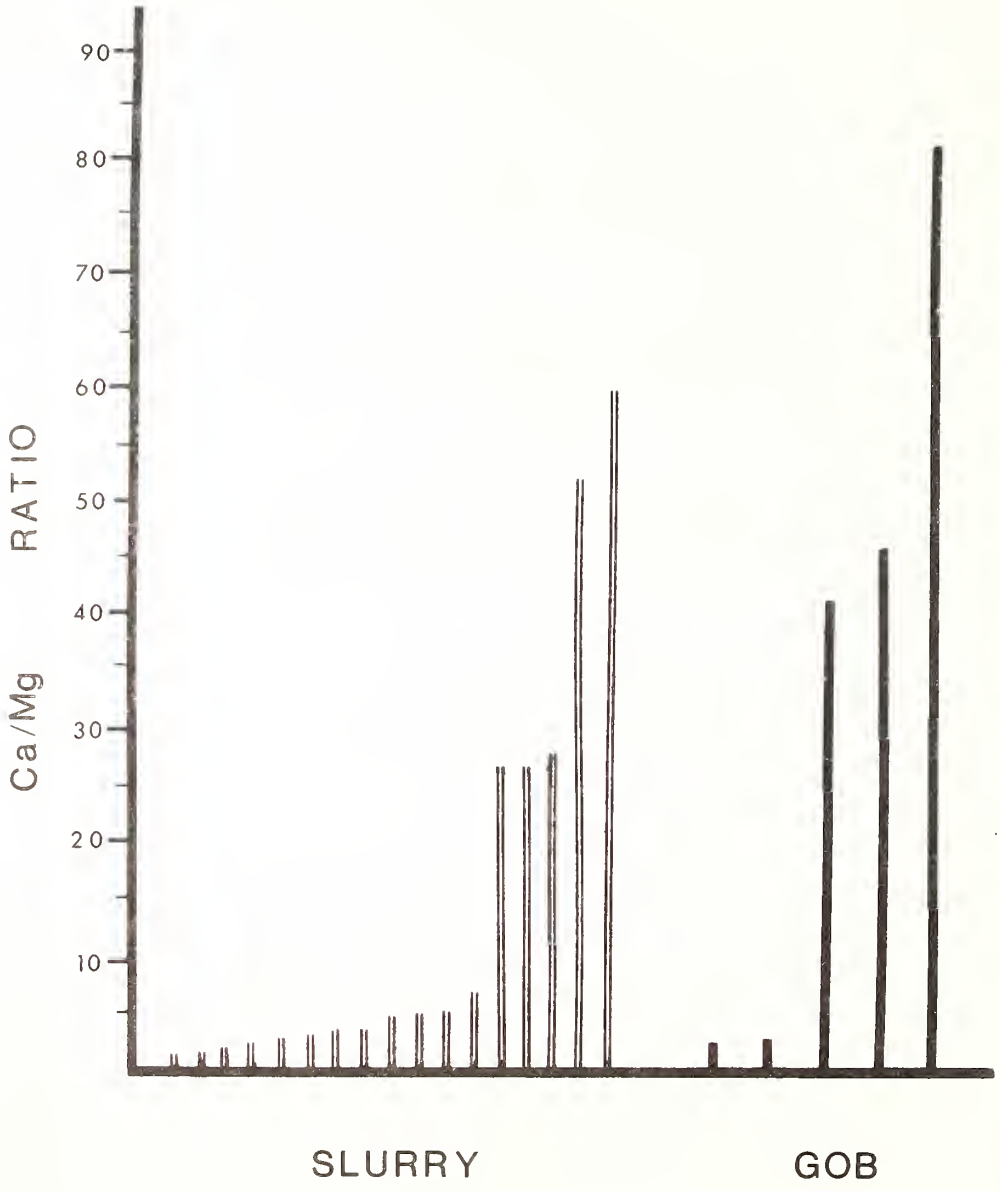


Fig. 13. Ratios of calcium to magnesium for slurry and gob refuse associated with surface mining for coal in Illinois.

samples) showed a ratio less than 1:1. Usually, the ratio of calcium to magnesium is low in extremely acid materials (Barnhisel and Massey 1969; Beyer and Hutnik 1969; Cummins et al. 1965; and Struthers 1964).

Both slurry and gob represented a hostile medium for plant growth as demonstrated by low pH and high reserve acidity, excessive concentrations of soluble salts, and low fertility. Furthermore, other researchers have noted that these materials often exhibit a low water-holding capacity and lack stability; slurry is especially subject to wind erosion during dry periods (Ramsey 1974; Smith et al. 1974). Such adverse properties have made refuse sites difficult and costly to reclaim (United States Department of the Interior 1974).

Haynes and Klimstra (1975) noted a limited effort to reclaim coal refuse sites in Illinois. As of 30 June 1971, most slurry and gob had not been covered (92 and 87 percent, respectively), and were not adequately vegetated (96 and 95 percent, respectively, with less than 25 percent vegetation density). Such sites occurred primarily in Fulton, Knox, and Peoria counties of Region I; Saline and Williamson counties of Region IV; and, Jackson, Perry, Randolph, and St. Clair counties of Region V (Figs. 14 and 15).

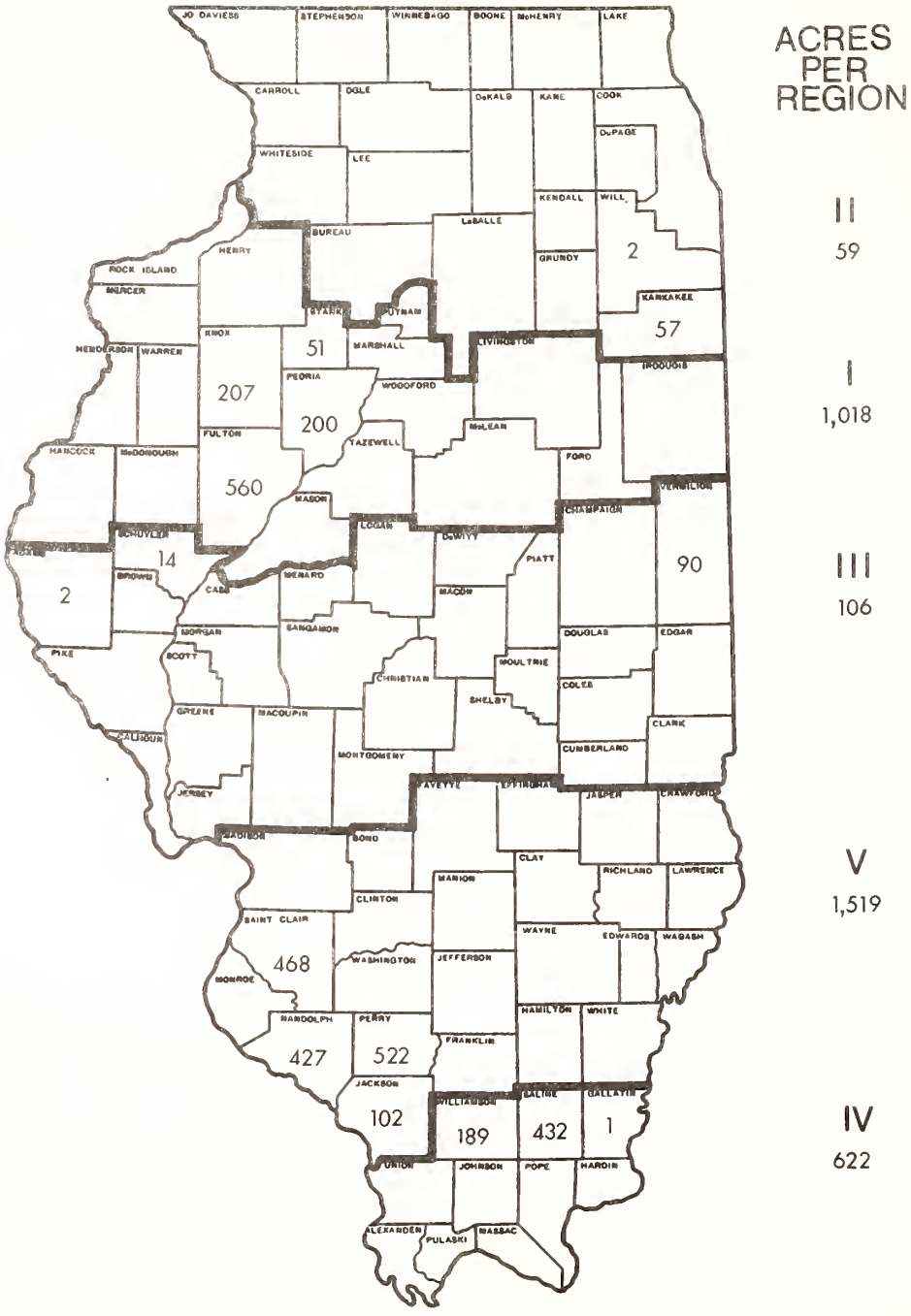


Fig. 14. Acreage of uncovered slurry disposal sites, according to County and Region as of 30 June 1971 (adapted from Haynes and Klimstra 1975).

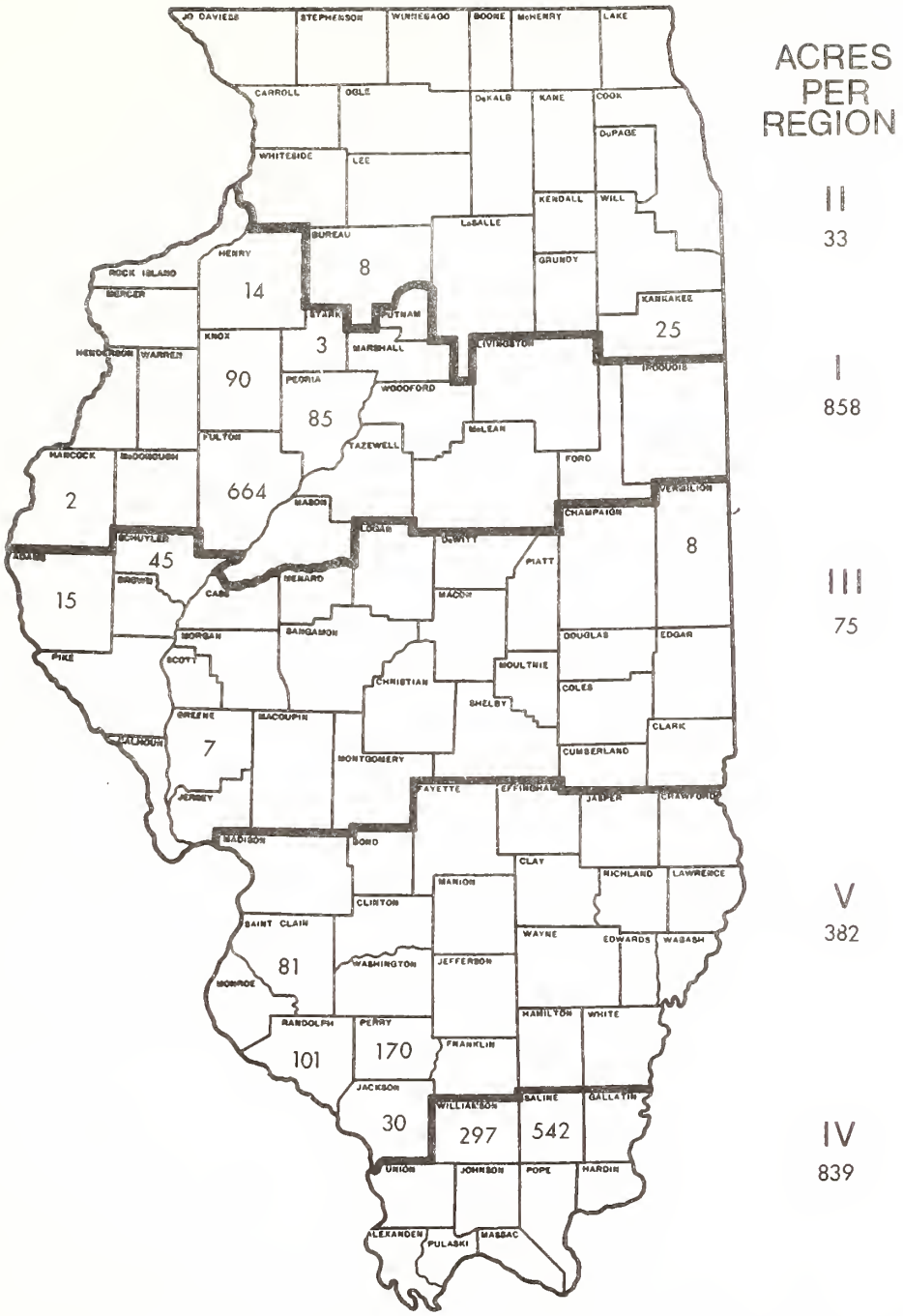


Fig. 15. Acreage of uncovered gob disposal sites, according to County and Region as of 30 June 1971 (adapted from Haynes and Klimstra 1975).

## SOME GENERAL COMMENTS ON RECLAMATION

The data presented and their analyses must be viewed as indicative of possible conditions as they are not precise and specific for every segment of land affected by surface mining. This caution emphasizes that the smallest spoilbank unit sampled was a section in size; and, that several samples were taken and pooled. Hence, the samples and their analyses neither represent all conditions that might have occurred nor yield anything but an "average" of what was collected and analyzed. To accommodate detailed information for specific site management will require further sampling and analysis for each acre under consideration. However, the information contained in this report establishes probable conditions and will aid directly in decision making in establishing priorities as based upon required techniques of management as well as estimation of costs.

We believe it important to emphasize that planned reclamation will necessitate careful inventory of any acreage under consideration. Exception to this are spoilbanks resulting from the wheel excavator, where uniformity is characteristic. However, most pre-law and many post-law spoils are the consequence of shovel and dragline extraction; and, at a time when there was little concern for the quality and condition of spoilbank materials. Only since the amended law of 1968 and the new legislation of 1971 has attention been given to censuring acid conditions in surface materials. However, the legislative amendments effective 1 July 1975 provide reasonable assurance that surface materials will be similar to those of the original unconsolidated stratum of the overburden.

One must rationalize with caution continued references to the shaping of spoilbanks that had not been graded previously or where such was minimal.

Appreciate that our study reveals a variety of characteristics of the top 6 inches; what lies below is essentially unknown. In a general way, characteristics of the original consolidated and unconsolidated strata are identified; also, the precise coal seam is known and the type of equipment employed is a matter of record. However, there is no day-by-day account for any mine regarding the manner in which the overburden was handled. And, limited information suggests that this not only varied between mines but also between individual equipment operators for each mine. Therefore, extreme and unknown variability is the rule as to the characteristics of conditions below 6 inches; but, surface aspects may yield some clues. Specifically, grading may create problems far more critical than those current. More importantly, current acceptable plant growth media may be destroyed by exposing toxic materials, eliminating acceptable soil texture, and destroying all the good consequences of weathering that occurred with the passing of time. The latter aspect is extremely important with respect to toxic conditions created in spoilbanks as the result of carelessness in handling the overburden when the law did not fully prohibit this practice. There is clear evidence for Illinois that time has enhanced establishment of vegetation on once barren areas (McGrath 1972); and, in many cases it can be expected that grading will do little more than open old wounds. Although certain practices hold promise for resolution of toxic conditions, there are too many unknowns and problems (not the least of which is cost) to pursue a full effort in reclamation that includes massive leveling of all or even very many areas which now show good sign of natural revegetation several years after being surface mined.

No great emphasis was placed on sampling gob and slurry as little variability was expected for given sites; and, generally, this refuse at one mine is fairly characteristic of others. This is especially true for gob. However, these sites are clearly problem situations wherever they

occur, if for no other reason than esthetics. Gob refuse, as exposed in a pile, is a constant source of acid production; this is also true for some slurry situations. Reclamation should emphasize these sites and accommodate two approaches, secondary and tertiary recovery of coal and covering residues with soil suitable for revegetation. The conditions exhibited by these refuse sites do not permit many alternatives in reducing the unattractiveness as well as providing productive use.

For land affected by coal surface mining in Illinois, Klimstra and Terpening (1974) and Haynes and Klimstra (1975) describe and identify 17,67 acres as toxic and/or barren sites. The methods for reclamation of these areas, at what justified cost, and over what period of time, are questions to be accommodated. The literature on this subject is extensive and reflects many ideas and techniques for resolving such problems. Klimstra and Terpening (1974) offered limited suggestions; significant contributions are provided in a collection of papers edited by Hutnik and Davis (1973) and symposia sponsored by Bituminous Coal Research, Inc. (Research and Applied Technology Symposium on Mined-Land Reclamation for 1973 and 1974). There are, of course, many others which provide important information and suggestions.

The existing toxicities and unstable conditions in spoilbank and refuse materials in Illinois must be dealt with. There have been at least two considerations applicable to such conditions. One approach has been to identify specific species of plants showing an adaptability to existing conditions. This technique has yielded reasonable results; however, at best only a few plants tolerate a growth medium with a pH of less than 4.0 (see Hutnik and Davis 1973). The second avenue has been to treat affected materials, correcting problem conditions and providing acceptable plant-

growth media. Such methods (used singularly and in combination) include:

1) Covering with place-land soil or adjacent spoilbank materials to eliminate production of acidity, provide a suitable growth medium, and improve stability

2) Allowing time for or enhancing leaching to remove excessive concentrations of soluble salts

3) Application of limestone to increase pH

4) Application of fertilizers to increase fertility

5) Application of sewage sludge, lime sludge, livestock residues, fly ash, and various mulches and chemical-binding agents to increase pH and fertility; and, to prevent wind and water erosion

6) Application of bactericides to suppress rapid oxidation of ferrous iron and subsequent production of acid.

Reclamation of some may be impossible because of inadequate technology and/or prohibitive cost. Recent studies in Pennsylvania have shown that reclamation costs for selected refuse disposal sites ranged from $1,800 to more than $15,000 per acre. Site preparation varied from $772 to $5,550 per acre, while covering with soil and planting ranged from $1,083 to $5,086 per acre (United States Department of the Interior 1973). When excessive costs necessitate a limited reclamation effort, vegetation screens or other barriers can provide some erosion protection and can conceal the area from view until reclamation effort becomes feasible. However, effective reclamation procedures for any area which is a source of pollution to nearby streams or other off-site areas may not permit delay.

Successful reclamation should emphasize long-term aspects through programs of land use that consider the best as well as the maximum potential use of each area (Klimstra and Jewell 1974; Riley 1973; Thirgood 1973; and Cary 1971). Other relevant factors such as future mining activity, ecology, social implications, and economics should be considered in order to

establish a clear purpose and provide a means of achieving that purpose (Thirgood 1973).

## SUMMARY

The Cooperative Wildlife Research Laboratory, Southern Illinois University at Carbondale, during 1970 and 1971 surveyed all lands in Illinois subjected to surface mining for coal through 30 June 1971. During the survey, 2,084 samples of spoilbank material and 22 samples of refuse materials (slurry and gob) were collected for determination and analysis of selected chemical and physical properties. This publication reports the results of these analyses and establishes a variety of parameters useful for reclamation and/or use of lands disturbed by coal surface mining.

The textures of Illinois spoilbank materials were variable; but, most samples were various kinds of loams of which silt loam, sandy loam, and loam textures represented 95 percent of the samples.

Although some surface materials from all mined areas yielded a pH of less than 4.1 (5 percent of the samples), most (89 percent) revealed a pH ranging from 5.1 to 8.1; seven percent had a pH ranging from 4.1 to 5.1. Spoil materials that yielded a pH less than 4.1 revealed properties deleterious to most vegetation; spoils with a pH of 4.1 to 5.1 often showed some adverse properties. Such properties included high exchangeable acidity and soluble salts; possibly toxic concentrations of soluble sulfate, iron, manganese, and aluminum; and, low base saturations, potassium, calcium, calcium to magnesium ratios, and organic matter to nitrogen ratios.

Average levels of magnesium and sodium were adequate in all spoils, while mean amounts of organic matter and nitrogen were low. Plant-available phosphorus was adequate in all spoils that exhibited a pH less than 6.1; but, it was low in other spoils. Some of the analyses for organic matter, nitrogen, phosphorus, calcium, magnesium, and iron may have been

inaccurate due to interactions between certain ions and chemical extractants used. Hence, the utilization of standard tests adapted for agricultural soils to determine chemical properties of mine spoils deserves additional study.

Although some spoilbanks associated with every coal seam were poorly vegetated and yielded a low pH and related adverse chemical properties, those which occurred primarily in Grundy and LaSalle counties (Region II), Schuyler County (Region III), Saline and Williamson counties (Region IV), and Jackson County (Region V) most often demonstrated such properties. Coal seams associated with these areas were the Colchester No. 2 in LaSalle and Grundy counties; the Springfield No. 5 in Schuyler County; the Harrisburg No. 5 and DeKoven and Davis No. 3 in Saline and Williamson counties; and, the Harrisburg No. 5 in Jackson County. The most adverse site conditions usually occurred in poorly vegetated spoils more than 10-years-old.

Large acreages in Will, Vermilion, and Perry counties (Regions II, III, and V, respectively) were also poorly vegetated but showed a pH greater than 5.1. Although not identified in this study, it was suggested that factors such as excessive erosion and stoniness, low percentage of soil-size particles, and other interacting factors resulted in the absence of vegetation.

Chemical analysis of slurry and gob refuse revealed that these materials provided a hostile medium for plant growth as evidenced by lack of vegetation, low pH and high reserve acidity, excessive concentrations of soluble salts, and low fertility. Unreclaimed refuse sites occurred primarily in Fulton, Knox, and Peoria counties of Region I; Saline and Williamson counties of Region IV; and, Jackson, Perry, Randolph, and St. Clair counties of Region V.

Some general considerations concerning reclamation with specific emphasis on problem spoilbanks and on refuse sites were presented.

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# APPENDIX

REPRE
MININ

Count

Adams
Brown
Burea
Crawf
Edgar
Fultc
Galla
Green
Grund
Hancc
Henry
Jacks
Jeffe
Johns
Kanka
Knox
LaSal
Marsh
McDor
Menar
Merce
Peori
Perry
Pope
Randc
Salir
Schuy
Scott
Stark
St. C
Vermi
Wabas
Will
Willi

Regic

Illir

Perce
Total

[a]See

TABLE A

REPRESENTATION OF SOIL SAMPLES BY COUNTY ACCORDING TO ASPECTS OF VEGETATION, EXTENT OF GRADING, TYPE OF UTILIZATION AND COAL SEAM EXTRACTED FOR LANDS IN ILLINOIS SUBJECTED TO SURFACE MINING FOR COAL.

| | | VEGETATION DENSITY | | | | | | LEGUMES | | | DEGREE OF GRADING | | | TYPE OF UTILIZATION | | | | | | COAL SEAMS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | < 25% | | | > 25% | | | | | | | | | | | | | | | | | | | | | | |
| | | AGE | | | AGE | | | | | | | | | | | | | | | | | | | | | | |
| County | No. of Samples | < 3 yra. | 3-10 yra. | > 10 yra. | < 3 yra. | 3-10 yra. | > 10 yra. | Present | Absent | None | Strike Off | Rolling or Level | None | Active Mine | Pasture or Hay | Other Crop | Recreation | Other | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Not Determined or Other |
| | | No. of samples | | | | | | | | | | | | | | | | | | | | | | | | | |
| Adams | 5 | 0 | 1 | 0 | 0 | 0 | 4 | 1 | 4 | 4 | 1 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| Brown | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Bureau | 50 | 1 | 1 | 2 | 0 | 8 | 38 | 3 | 47 | 26 | 9 | 15 | 20 | 0 | 26 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 0 |
| Crawford | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Edgar | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Fulton | 529 | 55 | 16 | 4 | 8 | 123 | 323 | 197 | 332 | 184 | 50 | 295 | 177 | 4 | 279 | 28 | 40 | 1 | 0 | 27 | 0 | 0 | 435 | 66 | 1 | 0 |
| Gallatin | 23 | 2 | 9 | 5 | 0 | 3 | 4 | 1 | 22 | 19 | 1 | 3 | 20 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 8 | 0 | 0 |
| Greene | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Grundy | 56 | 0 | 3 | 15 | 0 | 3 | 35 | 6 | 50 | 50 | 1 | 5 | 20 | 0 | 0 | 0 | 34 | 2 | 0 | 48 | 0 | 8 | 0 | 0 | 0 | 0 |
| Hancock | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 2 | 2 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Henry | 51 | 0 | 0 | 2 | 0 | 0 | 49 | 0 | 51 | 31 | 9 | 11 | 12 | 0 | 28 | 0 | 9 | 2 | 0 | 51 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jackson | 61 | 1 | 5 | 11 | 0 | 8 | 36 | 3 | 58 | 46 | 12 | 3 | 26 | 1 | 28 | 0 | 2 | 4 | 0 | 0 | 0 | 0 | 33 | 28 | 0 | 0 |
| Jefferson | 3 | 0 | 0 | 0 | 1 | 2 | 0 | 1 | 2 | 2 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Johnson | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 2 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Kankakee | 15 | 0 | 0 | 1 | 0 | 0 | 14 | 4 | 11 | 15 | 0 | 0 | 2 | 0 | 0 | 0 | 12 | 1 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 |
| Knox | 236 | 12 | 5 | 2 | 0 | 53 | 164 | 74 | 162 | 64 | 86 | 86 | 59 | 12 | 139 | 4 | 20 | 2 | 0 | 0 | 0 | 0 | 41 | 195 | 0 | 0 |
| LaSalle | 25 | 1 | 0 | 14 | 0 | 0 | 10 | 2 | 23 | 23 | 0 | 2 | 24 | 0 | 0 | 0 | 0 | 1 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 |
| Marshall | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| McDonough | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Menard | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Mercer | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Peoria | 69 | 13 | 0 | 0 | 11 | 30 | 15 | 49 | 20 | 18 | 16 | 35 | 22 | 2 | 45 | 0 | 0 | 0 | 0 | 17 | 0 | 0 | 1 | 51 | 0 | 0 |
| Perry | 214 | 12 | 20 | 5 | 0 | 43 | 134 | 37 | 177 | 110 | 77 | 27 | 131 | 4 | 55 | 2 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 214 | 0 | 0 |
| Pope | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Randolph | 68 | 2 | 1 | 0 | 7 | 25 | 33 | 13 | 55 | 32 | 31 | 5 | 40 | 0 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 53 | 0 | 0 |
| Saline | 144 | 2 | 30 | 25 | 1 | 25 | 61 | 4 | 140 | 102 | 34 | 8 | 132 | 2 | 10 | 0 | 0 | 0 | 4 | 0 | 6 | 0 | 44 | 71 | 1 | 18 |
| Schuyler | 36 | 0 | 4 | 5 | 0 | 8 | 19 | 15 | 21 | 25 | 7 | 4 | 11 | 0 | 25 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 26 | 0 | 0 | 0 |
| Scott | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Stark | 22 | 3 | 2 | 0 | 4 | 9 | 4 | 18 | 4 | 1 | 1 | 20 | 5 | 0 | 15 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 0 | 0 |
| St. Clair | 118 | 3 | 0 | 0 | 5 | 35 | 75 | 34 | 84 | 35 | 63 | 20 | 65 | 1 | 45 | 1 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 115 | 0 | 3 |
| Vermilion | 64 | 1 | 1 | 1 | 3 | 9 | 49 | 1 | 63 | 46 | 7 | 11 | 39 | 0 | 1 | 0 | 21 | 3 | 0 | 0 | 0 | 0 | 0 | 22 | 42 | 0 |
| Wabash | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Will | 46 | 1 | 3 | 3 | 0 | 1 | 38 | 7 | 39 | 45 | 0 | 1 | 18 | 0 | 0 | 0 | 27 | 1 | 0 | 46 | 0 | 0 | 0 | 0 | 0 | 0 |
| Williamson | 232 | 25 | 22 | 46 | 2 | 30 | 107 | 21 | 211 | 167 | 51 | 14 | 210 | 0 | 18 | 0 | 0 | 4 | 0 | 0 | 34 | 0 | 94 | 102 | 0 | 2 |
| Region[a] I | 912 | 83 | 23 | 9 | 23 | 215 | 559 | 338 | 574 | 302 | 162 | 448 | 277 | 18 | 509 | 32 | 71 | 5 | 0 | 98 | 0 | 0 | 477 | 334 | 2 | 1 |
| II | 192 | 3 | 7 | 35 | 0 | 12 | 135 | 22 | 170 | 159 | 10 | 23 | 84 | 0 | 26 | 0 | 73 | 9 | 0 | 134 | 0 | 8 | 0 | 50 | 0 | 0 |
| III | 110 | 1 | 6 | 8 | 3 | 18 | 74 | 17 | 93 | 80 | 15 | 15 | 57 | 0 | 29 | 0 | 21 | 3 | 0 | 17 | 0 | 0 | 27 | 22 | 42 | 2 |
| IV | 404 | 33 | 62 | 76 | 3 | 58 | 172 | 26 | 378 | 289 | 88 | 27 | 367 | 4 | 29 | 0 | 0 | 4 | 6 | 0 | 40 | 0 | 153 | 181 | 1 | 23 |
| V | 466 | 18 | 26 | 16 | 13 | 113 | 280 | 89 | 377 | 226 | 184 | 56 | 267 | 6 | 156 | 3 | 29 | 5 | 0 | 0 | 0 | 0 | 48 | 410 | 0 | 8 |
| Illinois | 2,084 | 138 | 124 | 144 | 42 | 416 | 1,220 | 492 | 1,592 | 1,056 | 459 | 569 | 1,052 | 28 | 749 | 35 | 194 | 26 | 6 | 249 | 40 | 8 | 705 | 997 | 45 | 34 |
| Percent of Total Samples | -- | 7 | 6 | 7 | 2 | 20 | 58 | 24 | 76 | 51 | 22 | 27 | 51 | 1 | 36 | 2 | 9 | 1 | < 1 | 12 | 2 | < 1 | 34 | 48 | 2 | 2 |

[a]See Fig. 3.

TABLE B

LOCATION AND DESCRIPTION OF COLLECTION SITES FOR SAMPLES OF SLURRY AND GOB REFUSE FROM LANDS AFFECTED BY SURFACE MINING COAL IN ILLINOIS.

| Sample No. | County | Township, Range, and Section | Description |
|---|---|---|---|
| 38 | Peoria | T9N-R6E-S25 | Uncovered and barren slurry; 9 yrs. old. |
| 146 | Williamson | T9S-R3E-S9 | Uncovered and barren slurry; greater than 10 yrs. old. |
| 191 | Williamson | T10S-R4E-S13 | Uncovered and barren slurry; greater than 10 yrs. old. |
| 260 | Williamson | T9S-R2E-S4 | Uncovered slurry with scattered dead trees and Phragmites sp. dense around periphery; 19 yrs. old. |
| 280 | Williamson | T8S-R1E-S31 | Uncovered and barren slurry; greater than 10 yrs. old. |
| 300 | Williamson | T9S-R2E-S4 | Uncovered and barren slurry; 19 yrs. old. |
| 439 | Fulton | T6N-R3E-S35 | Uncovered and barren slurry; greater than 22 yrs. old. |
| 616 | Fulton | T6N-R4E-S28 | Uncovered slurry with invasion of weeds and some trees; greater than 10 yrs. old. |
| 1020 | Perry | T6S-R2W-S26 | Uncovered and barren slurry; age unknown. |
| 1038 | Perry | T5S-R2W-S26 | Uncovered and barren slurry; greater than 10 yrs. old. |
| 1061 | Perry | T6S-R2W-S20 | Uncovered and barren slurry; 22 yrs. old. |
| 1262 | Schuyler | T2N-R1W-S25 | Uncovered and barren slurry; age unknown. |

TABLE B. Continued

| Sample No. | County | Township, Range, and Section | Description |
|---|---|---|---|
| 1797 | Knox | T12N-R4E-S17 | Uncovered and barren slurry - active mine area; 2 yrs. old. |
| 1833 | Knox | T12N-R3E-S36 | Uncovered and barren slurry; 32 yrs. old. |
| 2003 | Saline | T10S-R6E-S9 | Uncovered and barren slurry; greater than 13 yrs. old. |
| 2063 | Gallatin | T10S-R9E-S4 | Uncovered and barren slurry; 5 yrs. old. |
| 2508 | Saline | T9S-R5E-S20 | Uncovered and barren slurry; greater than 10 yrs. old. |
| 298 | Williamson | T9S-R4E-S36 | Uncovered and barren gob; greater than 10 yrs. old. |
| 731 | Fulton | T8N-R4E-S5 | Uncovered and barren gob; greater than 10 yrs. old. |
| 1045 | Perry | T5S-R2W-S25 | Uncovered and barren gob; greater than 10 yrs. old. |
| 1523 | Will | T32N-R9E-S17 | Uncovered and barren gob; age unknown. |
| 1980 | Saline | T9S-R5E-S19 | Uncovered and barren gob; 9 yrs. old. |

TABLE C

CODED VARIABLES USED TO SORT DATA OBTAINED FROM ANALYSIS OF SAMPLES OF SPOILBANK AND REFUSE MATERIALS COLLECTED FROM ILLINOIS LANDS SURFACE MINED FOR COAL

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Type of Material

Code 1--Spoil
Code 2--Slurry
Code 3--Gob

Regions

Code 1--Region I
Code 2--Region II
Code 3--Region III
Code 4--Region IV
Code 5--Region V

Counties

Code 01--Adams
Code 05--Brown
Code 06--Bureau
Code 17--Crawford
Code 23--Edgar
Code 29--Fulton
Code 30--Gallatin
Code 31--Greene
Code 32--Grundy
Code 34--Hancock
Code 37--Henry
Code 39--Jackson
Code 41--Jefferson
Code 44--Johnson
Code 46--Kankakee
Code 48--Knox
Code 50--LaSalle
Code 59--Marshall
Code 62--McDonough
Code 65--Menard
Code 66--Mercer
Code 72--Peoria
Code 73--Perry
Code 76--Pope
Code 79--Randolph
Code 82--Saline

Code 84--Schuyler
Code 85--Scott
Code 87--Stark
Code 88--St. Clair
Code 92--Vermilion
Code 93--Wabash
Code 99--Will
Code 100--Williamson

Coal Seams

Code 1--Rock Island No. 1
Code 2--Colchester No. 2
Code 3--DeKoven and Davis No. 3
Code 4--Summum No. 4
Code 5--Harrisburg and Springfield No. 5
Code 6--Herrin No. 6
Code 7--Danville No. 7
Code 8--Other or Unknown

pH Classes

Code 1--< 3.1
Code 2--3.1-4.0
Code 3--4.1-5.0
Code 4--5.1-6.0
Code 5--6.1-7.0
Code 6--7.1-8.0
Code 7--> 8.0

Vegetation and Age Classes

Code 1--< 25%, <3 yrs.
Code 2--< 25%, 3-10 yrs.
Code 3--< 25%, >10 yrs.
Code 4--> 25%, <3yrs.
Code 5--> 25%, 3-10 yrs.
Code 6--> 25%, >10 yrs.

Presence or Absence of Legumes

Code 1--Legumes Present
Code 2--Legumes Absent

Degree of Grading

Code 1--None
Code 2--Strike Off
Code 3--Graded to a Rolling or Level Topography

Types of Utilization

Code 1--None Observed
Code 2--Active Mine

Code 3--Pasture or Hay
Code 4--Other Crops
Code 5--Recreation
Code 6--Other

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TABLE D

SUMMATION, ACCORDING TO COUNTY, REGION, AND STATE, FOR LEVELS OF pH AND SOLUBLE SALTS AS RECORDED FOR SAMPLES OF SPOILBANK MATERIALS.

| County | No. of Samples | pH | Total Soluble Salts mmhos/cm | Soluble $SO_4$ ppm. | Soluble Fe ppm. | Soluble Mn ppm. | Soluble Al ppm. |
|---|---|---|---|---|---|---|---|
| Adams | 5 | | | | | | |
| Range | | 5.1-6.5 | 0.18-1.30 | 35.0-260.0 | 0.6-42.0 | 1.5-5.5 | 0.84-60.00 |
| Mean | | 5.8 | 0.65 | 141.5 | 10.1 | 3.1 | 14.77 |
| SD | | 0.51 | 0.60 | 103.75 | 17.93 | 1.97 | 25.33 |
| Brown | 1 | 4.3 | 0.36 | 180.0 | 4.8 | 2.5 | 7.98 |
| Bureau | 50 | | | | | | |
| Range | | 5.5-8.0 | 0.04-2.40 | 16.5-397.5 | 0.7-92.0 | 0.6-17.7 | 0.50-42.50 |
| Mean | | 7.4 | 0.67 | 142.0 | 7.9 | 1.6 | 3.85 |
| SD | | 0.62 | 0.58 | 115.77 | 14.99 | 2.35 | 6.09 |
| Crawford | 1 | 7.1 | 0.43 | 77.8 | 4.2 | 0.6 | 2.10 |
| Edgar | 1 | 4.6 | 0.11 | 163.5 | 2.3 | 0.8 | 2.52 |
| Fulton | 529 | | | | | | |
| Range | | 2.7-8.2 | 0.01-5.40 | 0.2-518.8 | 0.1-600.0 | 0.2-17.9 | 0.40-288.00 |
| Mean | | 7.4 | 0.58 | 81.8 | 7.0 | 1.9 | 3.05 |
| SD | | 6.62 | 0.64 | 92.23 | 29.77 | 2.53 | 13.13 |
| Gallatin | 23 | | | | | | |
| Range | | 3.5-7.8 | 0.14-2.30 | 12.5-370.0 | 0.4-200.0 | 1.8-11.0 | 0.59-93.60 |
| Mean | | 6.1 | 0.56 | 119.8 | 41.9 | 3.4 | 8.04 |
| SD | | 1.13 | 0.58 | 102.49 | 65.09 | 2.03 | 19.87 |

TABLE D. Continued

| County | No. of Samples | pH | Total Soluble Salts mmhos/cm | Soluble $SO_4$ ppm. | Soluble Fe ppm. | Soluble Mn ppm. | Soluble Al ppm. |
|---|---|---|---|---|---|---|---|
| Greene | 1 | 3.5 | 2.90 | 505.0 | 17.0 | 1.3 | 384.00 |
| Grundy | 56 | | | | | | |
| Range | | 3.1-7.7 | 0.30-4.10 | 16.5-505.0 | 0.4-190.0 | 0.8-17.4 | 0.42-1,464.00 |
| Mean | | 6.3 | 1.03 | 191.4 | 15.3 | 2.9 | 73.50 |
| SD | | 1.50 | 1.08 | 161.93 | 26.70 | 2.98 | 232.17 |
| Hancock | 2 | | | | | | |
| Range | | 4.5-4.7 | 2.10-2.50 | 287.5-370.0 | 3.2-4.2 | 7.0-15.2 | 2.52-7.98 |
| Mean | | 4.6 | 2.30 | 328.7 | 3.7 | 11.1 | 5.25 |
| SD | | 0.14 | 0.28 | 58.34 | 0.71 | 5.80 | 3.86 |
| Henry | 51 | | | | | | |
| Range | | 2.1-7.9 | 0.03-8.60 | 40.5-505.0 | 1.3-996.0 | 1.0-9.7 | 0.59-492.00 |
| Mean | | 7.3 | 0.95 | 174.5 | 24.6 | 1.6 | 13.17 |
| SD | | 0.80 | 1.29 | 104.67 | 138.93 | 1.22 | 69.12 |
| Jackson | 61 | | | | | | |
| Range | | 3.5-7.7 | 0.01-2.20 | 8.8-425.0 | 0.3-110.0 | 1.0-14.9 | 0.42-2,976.00 |
| Mean | | 5.8 | 0.67 | 160.2 | 14.9 | 3.6 | 69.66 |
| SD | | 1.29 | 0.74 | 127.70 | 23.80 | 3.34 | 387.69 |
| Jefferson | 3 | | | | | | |
| Range | | 3.3-4.7 | 0.44-3.30 | 180.0-505.0 | 1.8-6.6 | 2.0-5.0 | 4.62-492.00 |
| Mean | | 4.2 | 1.75 | 305.8 | 3.7 | 3.0 | 168.20 |
| SD | | 0.78 | 1.45 | 174.47 | 2.53 | 1.73 | 280.40 |

TABLE D. Continued

| County | No. of Samples | pH | Total Soluble Salts mmhos/cm | Soluble $SO_4$ ppm. | Soluble Fe ppm. | Soluble Mn ppm. | Soluble Al ppm. |
|---|---|---|---|---|---|---|---|
| Johnson | 4 | | | | | | |
| Range | | 3.8-6.0 | 0.06-2.30 | 16.5-348.0 | 1.8-145.0 | 2.7-3.0 | 2.36-288.0 |
| Mean | | 4.9 | 0.64 | 104.8 | 49.3 | 2.9 | 89.36 |
| SD | | 0.90 | 1.11 | 162.26 | 65.76 | 0.15 | 134.98 |
| Kankakee | 15 | | | | | | |
| Range | | 7.0-7.9 | 0.05-2.20 | 40.5-370.0 | 0.3-19.9 | 0.4-2.7 | 0.84-4.62 |
| Mean | | 7.4 | 0.76 | 161.7 | 3.6 | 1.7 | 2.44 |
| SD | | 0.33 | 0.65 | 77.48 | 5.49 | 0.64 | 1.13 |
| Knox | 236 | | | | | | |
| Range | | 3.8-8.1 | 0.02-3.10 | 10.0-425.0 | 0.3-135.0 | 0.6-11.0 | 0.50-93.60 |
| Mean | | 7.4 | 0.45 | 86.4 | 9.9 | 2.0 | 3.86 |
| SD | | 0.47 | 0.51 | 85.56 | 17.20 | 0.94 | 7.05 |
| LaSalle | 25 | | | | | | |
| Range | | 2.5-6.8 | 0.16-4.70 | 12.5-518.8 | 0.3-240.0 | 1.3-17.9 | 1.26-1,920.00 |
| Mean | | 4.2 | 2.09 | 329.5 | 27.8 | 4.5 | 320.50 |
| SD | | 1.47 | 1.24 | 174.9 | 52.41 | 5.43 | 539.26 |
| Marshall | 1 | 6.0 | 0.74 | 152.5 | 3.8 | 2.7 | 2.94 |
| McDonough | 1 | 7.8 | 0.25 | 11.3 | 3.2 | 0.4 | 0.42 |
| Menard | 1 | 7.7 | 0.42 | 113.8 | 3.2 | 0.8 | 0.84 |
| Mercer | 1 | 7.2 | 0.26 | 15.3 | 0.9 | 2.7 | 4.72 |

TABLE D. Continued

| County | No. of Samples | pH | Total Soluble Salts mmhos/cm | Soluble $SO_4$ ppm. | Soluble Fe ppm. | Soluble Mn ppm. | Soluble Al ppm. |
|---|---|---|---|---|---|---|---|
| Peoria | 69 | | | | | | |
| Range | | 4.9-8.2 | 0.10-2.60 | 8.8-397.5 | 0.1-250.0 | 0.4-14.9 | 0.42-7.56 |
| Mean | | 7.3 | 0.63 | 85.6 | 6.6 | 2.2 | 2.69 |
| SD | | 0.90 | 0.61 | 69.37 | 29.89 | 2.40 | 1.54 |
| Perry | 214 | | | | | | |
| Range | | 4.1-8.1 | 0.01-12.00 | 5.0-260.0 | 0.4-310.0 | 0.4-17.9 | 0.40-64.07 |
| Mean | | 7.3 | 0.70 | 61.6 | 5.9 | 1.4 | 3.19 |
| SD | | 0.69 | 1.06 | 51.37 | 23.33 | 1.31 | 6.74 |
| Pope | 1 | 5.3 | 0.10 | 38.8 | 2.3 | 2.7 | 3.54 |
| Randolph | 68 | | | | | | |
| Range | | 5.2-7.9 | 0.02-3.30 | 5.0-342.5 | 2.0-998.0 | 0.8-1.7 | 0.40-288.00 |
| Mean | | 7.3 | 0.46 | 52.2 | 20.2 | 1.1 | 7.07 |
| SD | | 0.70 | 0.54 | 49.78 | 120.52 | 0.23 | 34.62 |
| Saline | 144 | | | | | | |
| Range | | 3.2-7.6 | 0.01-4.90 | 8.8-505.0 | 0.3-140.0 | 0.6-16.5 | 0.40-1,120.00 |
| Mean | | 5.6 | 0.62 | 146.1 | 14.4 | 3.2 | 35.14 |
| SD | | 1.20 | 0.71 | 106.60 | 27.08 | 2.66 | 139.17 |
| Schuyler | 36 | | | | | | |
| Range | | 4.5-7.6 | 0.02-2.40 | 12.5-397.5 | 1.0-115.0 | 0.8-15.9 | 0.40-33.28 |
| Mean | | 6.5 | 0.51 | 112.4 | 5.7 | 2.2 | 2.85 |
| SD | | 1.09 | 0.59 | 99.64 | 18.76 | 3.16 | 5.47 |

TABLE D. Continued

| County | No. of Samples | pH | Total Soluble Salts mmhos/cm | Soluble $SO_4$ ppm. | Soluble Fe ppm. | Soluble Mn ppm. | Soluble Al ppm. |
|---|---|---|---|---|---|---|---|
| Scott | 1 | 4.1 | 0.26 | 177.3 | 4.0 | 1.3 | 3.36 |
| Stark | 22 | | | | | | |
| Range | | 6.9-8.2 | 0.10-1.10 | 35.0-206.3 | 0.4-2.8 | 1.8-5.4 | 0.84-4.62 |
| Mean | | 7.8 | 0.51 | 126.7 | 0.9 | 2.6 | 2.26 |
| SD | | 0.30 | 0.26 | 50.17 | 0.62 | 0.74 | 0.81 |
| St. Clair | 118 | | | | | | |
| Range | | 4.4-8.0 | 0.01-3.70 | 12.5-370.0 | 0.7-92.0 | 0.6-16.6 | 0.40-276.00 |
| Mean | | 7.3 | 0.54 | 88.7 | 11.4 | 1.8 | 5.55 |
| SD | | 0.64 | 0.68 | 88.13 | 18.26 | 1.44 | 26.45 |
| Vermilion | 64 | | | | | | |
| Range | | 4.3-8.0 | 0.02-3.80 | 13.8-397.5 | 0.4-92.0 | 0.4-11.2 | 0.42-56.72 |
| Mean | | 7.1 | 0.73 | 122.3 | 5.7 | 1.6 | 3.14 |
| SD | | 0.82 | 0.87 | 114.92 | 12.89 | 1.32 | 7.32 |
| Wabash | 1 | 4.4 | 0.10 | 260.0 | 0.9 | 10.3 | 16.68 |
| Will | 46 | | | | | | |
| Range | | 5.1-7.8 | 0.04-4.40 | 24.5-370.0 | 1.3-130.0 | 1.3-15.7 | 0.40-60.00 |
| Mean | | 7.2 | 0.64 | 122.3 | 15.0 | 2.2 | 5.95 |
| SD | | 0.65 | 0.75 | 90.98 | 22.62 | 2.29 | 11.51 |
| Williamson | 232 | | | | | | |
| Range | | 2.5-8.3 | 0.07-3.40 | 6.3-518.8 | 0.3-450.0 | 0.6-17.9 | 0.42-936.00 |
| Mean | | 5.8 | 0.64 | 145.4 | 29.7 | 3.6 | 24.10 |
| SD | | 1.37 | 0.64 | 131.72 | 71.48 | 3.34 | 92.44 |

TABLE D. Continued

| Region[a] | No. of Samples | pH | Total Soluble Salts mmhos/cm | Soluble $SO_4$ ppm. | Soluble Fe ppm. | Soluble Mn ppm. | Soluble Al ppm. |
|---|---|---|---|---|---|---|---|
| Region I | 912 | | | | | | |
| Range | | 2.1-8.2 | 0.01-8.60 | 0.2-518.8 | 0.1-996 | 0.2-17.9 | 0.40-492 |
| Mean | | 7.4 | 0.57 | 90.0 | 8.5 | 1.9 | 3.77 |
| SD | | 0.63 | 0.67 | 91.97 | 41.64 | 2.17 | 19.52 |
| Region II | 192 | | | | | | |
| Range | | 2.5-8.0 | 0.03-4.70 | 12.5-518.8 | 0.3-240 | 0.4-17.9 | 0.40-1,920 |
| Mean | | 6.6 | 0.96 | 177.7 | 14.0 | 2.5 | 65.78 |
| SD | | 1.49 | 1.00 | 146.23 | 27.84 | 3.13 | 250.59 |
| Region III | 110 | | | | | | |
| Range | | 3.5-8.0 | 0.02-3.80 | 12.5-505.0 | 0.4-115 | 0.4-15.9 | 0.40-384 |
| Mean | | 6.8 | 0.66 | 124.8 | 5.9 | 1.8 | 7.13 |
| SD | | 1.09 | 0.79 | 112.60 | 14.93 | 2.13 | 37.56 |
| Region IV | 404 | | | | | | |
| Range | | 2.5-8.3 | 0.01-4.90 | 6.3-518.8 | 0.3-450 | 0.6-17.9 | 0.40-1,120 |
| Mean | | 5.7 | 0.63 | 143.5 | 25.1 | 3.4 | 27.73 |
| SD | | 1.30 | 0.68 | 121.71 | 59.40 | 3.03 | 109.66 |
| Region V | 466 | | | | | | |
| Range | | 3.3-8.1 | 0.01-12.00 | 5.0-505.0 | 0.3-998 | 0.4-17.9 | 0.40-2,976 |
| Mean | | 7.1 | 0.62 | 81.9 | 10.5 | 1.8 | 14.06 |
| SD | | 0.96 | 0.87 | 85.13 | 50.26 | 1.87 | 143.32 |
| Illinois | 2,084 | | | | | | |
| Range | | 2.1-8.3 | 0.01-12.00 | 0.2-12.5 | 0.1-998 | 0.2-17.9 | 4.40-2,976 |
| Mean | | 6.9 | 0.63 | 108.5 | 12.5 | 2.2 | 16.6 |
| SD | | 1.09 | 0.80 | 111.53 | 38.81 | 2.47 | 112.13 |

[a]See Fig. 3

TABLE E

SUMMATION, ACCORDING TO COUNTY, REGION, AND STATE, FOR LEVELS OF ORGANIC MATTER, NITROGEN, PHOSPHORUS; AND PERCENTAGE OF SAND, SILT, AND CLAY AS RECORDED FOR SAMPLES OF SPOILBANK MATERIALS.

| County | No. of Samples | O.M. % | N[a] ppm. | P[b] ppm. | Texture[c] % Sand | % Silt | % Clay |
|---|---|---|---|---|---|---|---|
| Adams | 5 | | | | | | |
| Range | | 0.5-1.6 | 560-812 | 8-22 | 30-46 | 40-56 | 10-16 |
| Mean | | 1.0 | 638.4 | 13.6 | 39.6 | 47.6 | 12.8 |
| SD | | 0.43 | 99.78 | 5.32 | 7.93 | 6.39 | 2.68 |
| Brown | 1 | 1.8 | 964 | 12 | 44 | 42 | 14 |
| Bureau | 50 | | | | | | |
| Range | | 0.3-6.6 | 420-3,864 | 2-113 | 20-74 | 18-64 | 8-20 |
| Mean | | 2.0 | 1,047.2 | 14.6 | 38.8 | 48.1 | 13.1 |
| SD | | 1.29 | 664.55 | 21.61 | 11.83 | 10.38 | 2.86 |
| Crawford | 1 | 2.6 | 1,708 | 11 | 70 | 22 | 8 |
| Edgar | 1 | 1.1 | 868 | 24 | 46 | 36 | 18 |
| Fulton | 529 | | | | | | |
| Range | | 0.0-13.7 | 1-3,800 | 1-170 | 12-68 | 22-78 | 6-38 |
| Mean | | 1.7 | 1,121.8 | 9.2 | 35.0 | 53.1 | 11.9 |
| SD | | 1.34 | 598.27 | 12.34 | 9.09 | 8.90 | 4.65 |
| Gallatin | 23 | | | | | | |
| Range | | 0.6-5.6 | 336-2,464 | 4-70 | 26-66 | 24-66 | 6-20 |
| Mean | | 1.8 | 981.2 | 14.6 | 44.8 | 43.9 | 11.3 |
| SD | | 1.35 | 537.50 | 16.56 | 10.83 | 11.21 | 3.59 |
| Greene | 1 | 1.4 | 1,064 | 155 | 58 | 32 | 10 |

TABLE E. Continued

| County | No. of Samples | O.M. % | N[a] ppm. | P[b] ppm. | Texture[c] % Sand | % Silt | % Clay |
|---|---|---|---|---|---|---|---|
| Grundy | 56 | | | | | | |
| Range | | 0.6-7.5 | 252-4,928 | 2-67 | 18-94 | 4-72 | 6-14 |
| Mean | | 1.8 | 911.5 | 9.7 | 55.2 | 36.4 | 9.0 |
| SD | | 1.47 | 699.36 | 9.36 | 18.20 | 16.60 | 2.32 |
| Hancock | 2 | | | | | | |
| Range | | 1.1-1.2 | 642-1,635 | 12-24 | 34-42 | 48-54 | 10-12 |
| Mean | | 1.1 | 1,138.5 | 18.0 | 38.0 | 51.0 | 11.0 |
| SD | | 0.07 | 702.16 | 8.48 | 5.66 | 4.24 | 1.41 |
| Henry | 51 | | | | | | |
| Range | | 0.8-13.4 | 1-4,368 | 2-41 | 20-74 | 18-68 | 6-20 |
| Mean | | 3.0 | 1,129.0 | 7.6 | 41.9 | 46.2 | 11.9 |
| SD | | 1.86 | 621.05 | 7.71 | 14.76 | 13.27 | 3.18 |
| Jackson | 61 | | | | | | |
| Range | | 0.2-14.5 | 364-4,508 | 2-50 | 14-56 | 32-78 | 6-24 |
| Mean | | 1.7 | 914.4 | 12.9 | 42.4 | 46.3 | 11.4 |
| SD | | 2.40 | 710.37 | 9.40 | 8.88 | 8.83 | 2.86 |
| Jefferson | 3 | | | | | | |
| Range | | 0.7-2.4 | 616-1,596 | 5-30 | 28-48 | 38-62 | 8-14 |
| Mean | | 1.4 | 980.0 | 15.3 | 39.3 | 50.0 | 10.7 |
| SD | | 0.89 | 536.40 | 13.05 | 10.26 | 12.00 | 3.05 |
| Johnson | 4 | | | | | | |
| Range | | 0.5-4.6 | 392-1,120 | 2-5 | 32-58 | 32-58 | 8-16 |
| Mean | | 1.8 | 665.0 | 3.5 | 44.5 | 44.5 | 11.0 |
| SD | | 1.89 | 348.50 | 1.29 | 10.75 | 10.75 | 3.46 |

TABLE E. Continued

| County | No. of Samples | O.M. % | N[a] ppm. | P[b] ppm. | Texture[c] % Sand | % Silt | % Clay |
|---|---|---|---|---|---|---|---|
| Kankakee | 15 | | | | | | |
| Range | | 0.9-3.2 | 224-1,232 | 2-8 | 20-58 | 32-70 | 8-18 |
| Mean | | 1.8 | 668.3 | 3.9 | 43.6 | 44.3 | 12.1 |
| SD | | 0.77 | 262.85 | 1.75 | 10.09 | 9.56 | 2.45 |
| Knox | 236 | | | | | | |
| Range | | 0.4-10.6 | 1-5,516 | 2-67 | 20-64 | 28-70 | 4-20 |
| Mean | | 2.0 | 1,213.4 | 10.2 | 39.0 | 50.3 | 10.7 |
| SD | | 1.58 | 757.41 | 9.33 | 8.98 | 7.92 | 2.59 |
| LaSalle | 25 | | | | | | |
| Range | | 0.2-5.8 | 360-3,380 | 3-54 | 14-56 | 20-72 | 6-40 |
| Mean | | 1.5 | 1,026.9 | 25.2 | 32.0 | 47.1 | 20.9 |
| SD | | 1.29 | 661.49 | 16.66 | 11.79 | 17.26 | 10.89 |
| Marshall | 1 | 2.6 | 1,109 | 47 | 52 | 36 | 12 |
| McDonough | 1 | 0.8 | 1,752 | 3 | 38 | 52 | 10 |
| Menard | 1 | 0.7 | 759 | 8 | 36 | 54 | 10 |
| Mercer | 1 | 0.7 | 252 | 30 | 58 | 34 | 8 |
| Peoria | 69 | | | | | | |
| Range | | 0.2-5.4 | 280-2,300 | 2-26 | 8-48 | 32-74 | 6-40 |
| Mean | | 1.3 | 778.3 | 7.9 | 28.0 | 49.0 | 23.0 |
| SD | | 0.98 | 435.77 | 6.10 | 9.00 | 9.00 | 7.00 |

TABLE E. Continued

| County | No. of Samples | O.M. % | N[a] ppm. | P[b] ppm. | Texture[c] % Sand | % Silt | % Clay |
|---|---|---|---|---|---|---|---|
| Perry | 214 | | | | | | |
| Range | | 0.2-13.4 | 56-9,828 | 2-52 | 26-60 | 32-64 | 6-16 |
| Mean | | 1.5 | 874.0 | 8.2 | 44.5 | 46.4 | 9.1 |
| SD | | 1.26 | 761.25 | 6.30 | 6.36 | 6.36 | 1.83 |
| Pope | 1 | 0.5 | 280 | 3 | 42 | 50 | 8 |
| Randolph | 68 | | | | | | |
| Range | | 0.3-9.9 | 132-3,247 | 2-58 | 30-82 | 10-58 | 8-14 |
| Mean | | 2.0 | 980.2 | 11.2 | 45.8 | 44.5 | 9.6 |
| SD | | 1.77 | 618.92 | 10.78 | 8.32 | 8.32 | 1.34 |
| Saline | 144 | | | | | | |
| Range | | 0.6-12.0 | 84-4,172 | 1-93 | 24-86 | 6-66 | 6-20 |
| Mean | | 2.0 | 1,149.7 | 16.1 | 46.5 | 42.5 | 10.9 |
| SD | | 1.64 | 613.29 | 15.61 | 12.16 | 12.34 | 2.28 |
| Schuyler | 36 | | | | | | |
| Range | | 0.4-4.0 | 364-2,324 | 3-39 | 18-58 | 34-72 | 6-26 |
| Mean | | 1.3 | 730.3 | 14.2 | 38.5 | 50.2 | 11.3 |
| SD | | 0.66 | 353.88 | 8.22 | 9.03 | 8.70 | 4.25 |
| Scott | 1 | 1.1 | 784 | 80 | 62 | 26 | 12 |
| Stark | 22 | | | | | | |
| Range | | 0.3-2.1 | 240-1,120 | 2-17 | 16-52 | 34-72 | 10-26 |
| Mean | | 0.9 | 529.1 | 6.8 | 29.0 | 51.4 | 19.5 |
| SD | | 0.51 | 223.9 | 3.48 | 9.05 | 9.64 | 3.95 |

TABLE E. Continued

| County | No. of Samples | O.M. % | N[a] ppm. | P[b] ppm. | Texture[c] % Sand | % Silt | % Clay |
|---|---|---|---|---|---|---|---|
| St. Clair | 118 | | | | | | |
| Range | | 0.3-9.9 | 84-4,172 | 2-133 | 26-76 | 18-66 | 4-16 |
| Mean | | 1.5 | 839.0 | 16.3 | 45.5 | 45.4 | 9.1 |
| SD | | 1.46 | 627.67 | 16.51 | 10.36 | 10.13 | 1.88 |
| Vermilion | 64 | | | | | | |
| Range | | 0.3-9.9 | 252-3,164 | 2-37 | 20-80 | 12-62 | 6-36 |
| Mean | | 1.8 | 938.0 | 7.6 | 48.3 | 39.2 | 12.3 |
| SD | | 1.47 | 527.81 | 7.41 | 11.80 | 10.04 | 4.94 |
| Wabash | 1 | 2.4 | 896 | 20 | 54 | 36 | 10 |
| Will | 46 | | | | | | |
| Range | | 0.4-4.6 | 280-2,128 | 2-41 | 18-96 | 14-68 | 4-22 |
| Mean | | 1.9 | 908.2 | 7.1 | 47.7 | 41.0 | 12.4 |
| SD | | 0.82 | 412.68 | 6.26 | 17.73 | 14.34 | 3.84 |
| Williamson | 232 | | | | | | |
| Range | | 0.0-8.2 | 27-4,420 | 2-190 | 20-84 | 10-66 | 6-34 |
| Mean | | 1.4 | 935.3 | 14.6 | 40.9 | 39.8 | 19.3 |
| SD | | 1.22 | 579.60 | 23.05 | 11.50 | 9.21 | 6.00 |

TABLE E. Continued

| Region[d] | No. of Samples | O.M. % | N[a] ppm. | P[b] ppm. | Texture[c] % Sand | % Silt | % Clay |
|---|---|---|---|---|---|---|---|
| Region I | 912 | | | | | | |
| Range | | 0.0-13.7 | 1-5,516 | 1-170 | 8-74 | 18-78 | 4-40 |
| Mean | | 1.8 | 1,105.4 | 9.3 | 35.8 | 51.5 | 12.6 |
| SD | | 1.44 | 642.70 | 10.95 | 10.01 | 9.21 | 5.45 |
| Region II | 192 | | | | | | |
| Range | | 0.2-7.5 | 224-4,928 | 2-113 | 14-96 | 4-72 | 4-40 |
| Mean | | 1.8 | 942.1 | 11.9 | 45.2 | 42.6 | 12.6 |
| SD | | 1.22 | 603.81 | 15.05 | 17.11 | 14.85 | 5.89 |
| Region III | 110 | | | | | | |
| Range | | 0.3-9.9 | 252-3,164 | 2-155 | 18-80 | 12-72 | 6-36 |
| Mean | | 1.6 | 854.1 | 12.2 | 44.8 | 43.1 | 12.1 |
| SD | | 1.24 | 462.13 | 17.29 | 11.65 | 10.77 | 4.57 |
| Region IV | 404 | | | | | | |
| Range | | 0.0-12.0 | 27-4,420 | 1-190 | 20-86 | 6-66 | 6-34 |
| Mean | | 1.6 | 1,010.1 | 15.0 | 43.3 | 41.2 | 15.5 |
| SD | | 1.42 | 596.19 | 20.21 | 11.95 | 10.71 | 6.28 |
| Region V | 466 | | | | | | |
| Range | | 0.2-14.5 | 56-9,828 | 2-133 | 14-82 | 10-78 | 4-24 |
| Mean | | 1.6 | 888.5 | 11.4 | 44.7 | 45.8 | 9.5 |
| SD | | 1.58 | 699.75 | 11.27 | 8.30 | 8.19 | 2.09 |
| Illinois | 2,084 | | | | | | |
| Range | | 0.0-14.5 | 1-9,828 | 1-190 | 8-96 | 4-78 | 4-40 |
| Mean | | 1.7 | 1,010.1 | 11.3 | 40.6 | 47.0 | 12.4 |
| SD | | 1.38 | 600.92 | 14.95 | 11.80 | 10.75 | 4.86 |

[a]Total nitrogen.
[b]Bray #1.
[c]See Fig. 2.
[d]See Fig. 2.

TABLE F

SUMMATION, ACCORDING TO COUNTY, REGION, AND STATE, FOR EXCHANGEABLE CATIONS AS RECORDED FOR SAMPLES OF SPOILBANK MATERIALS.

| County | No. of Samples | Exchangeable K | Ca | Mg | Na | Fe | Mn | H | Al |
|---|---|---|---|---|---|---|---|---|---|
| | | meq/100 g | | | | | | | |
| Adams | 5 | | | | | | | | |
| Range | | 0.23-0.41 | 3.15-6.50 | 3.13-6.88 | 0.30-0.54 | 0.009-0.027 | 0.007-0.124 | 0.0-3.4 | 0.278-0.667 |
| Mean | | 0.30 | 4.49 | 4.39 | 0.41 | 0.018 | 0.056 | 1.2 | 0.412 |
| SD | | 0.07 | 1.45 | 1.57 | 0.09 | 0.006 | 0.043 | 1.40 | 0.160 |
| Brown | 1 | 0.17 | 1.95 | 0.67 | 0.52 | 0.028 | 0.036 | 20.0 | 8.676 |
| Bureau | 50 | | | | | | | | |
| Range | | 0.31-0.78 | 5.00-41.25 | 1.19-8.54 | 0.24-0.50 | 0.013-0.024 | 0.010-0.330 | 0.0-14.0 | 0.060-2.450 |
| Mean | | 0.35 | 12.37 | 3.40 | 0.37 | 0.017 | 0.060 | 0.4 | 0.440 |
| SD | | 0.13 | 5.72 | 1.27 | 0.05 | 0.003 | 0.050 | 2.14 | 0.360 |
| Crawford | 1 | 0.32 | 11.25 | 1.13 | 0.39 | 0.010 | 0.055 | 0.0 | 0.278 |
| Edgar | 1 | 0.28 | 0.75 | 1.19 | 0.37 | 0.009 | 0.028 | 18.0 | 6.118 |
| Fulton | 529 | | | | | | | | |
| Range | | 0.06-1.49 | 2.50-41.25 | 0.89-10.63 | 0.22-1.09 | 0.001-1.119 | 0.004-0.833 | 0.0-32.0 | 0.056-4.839 |
| Mean | | 0.33 | 10.40 | 4.43 | 0.42 | 0.035 | 0.045 | 0.3 | 0.383 |
| SD | | 0.12 | 3.25 | 1.51 | 0.09 | 0.048 | 0.055 | 2.22 | 0.434 |
| Gallatin | 23 | | | | | | | | |
| Range | | 0.09-0.51 | 0.35-16.85 | 0.33-7.50 | 0.24-0.43 | 0.005-0.016 | 0.007-0.211 | 0.0-19.0 | 0.167-4.394 |
| Mean | | 0.26 | 6.49 | 3.96 | 0.34 | 0.012 | 0.057 | 2.3 | 0.612 |
| SD | | 0.10 | 3.69 | 1.78 | 0.05 | 0.004 | 0.049 | 4.47 | 1.027 |

TABLE F. Continued

| County | No. of Samples | Exchangeable | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | K | Ca | Mg | Na | Fe | Mn | H | Al |
| | | meq/100 g | | | | | | | |
| Greene | 1 | 0.13 | 14.05 | 3.33 | 0.33 | 0.025 | 0.240 | 22.0 | 5.006 |
| Grundy | 56 | | | | | | | | |
| Range | | 0.03-0.47 | 1.58-21.80 | 0.89-8.54 | 0.26-0.61 | 0.008-1.396 | 0.004-0.817 | 0.0-26.0 | 0.110-9.230 |
| Mean | | 0.22 | 7.04 | 3.41 | 0.37 | 0.041 | 0.095 | 4.5 | 1.590 |
| SD | | 0.11 | 4.04 | 1.74 | 0.06 | 0.184 | 0.171 | 7.9 | 2.280 |
| Hancock | 2 | | | | | | | | |
| Range | | 0.23-0.32 | 7.25-8.25 | 3.74-6.04 | 0.48-0.61 | 0.030-0.030 | 0.045-0.167 | 5.0-14.0 | 1.279-3.726 |
| Mean | | 0.28 | 7.75 | 4.89 | 0.54 | 0.030 | 0.106 | 9.5 | 2.503 |
| SD | | 0.06 | 0.71 | 1.63 | 0.09 | 0.000 | 0.086 | 6.36 | 1.730 |
| Henry | 51 | | | | | | | | |
| Range | | 0.06-0.56 | 9.25-54.50 | 0.63-8.33 | 0.33-0.54 | 0.012-2.041 | 0.022-0.146 | 0.0-40.0 | 0.167-3.373 |
| Mean | | 0.39 | 17.65 | 3.23 | 0.41 | 0.055 | 0.068 | 0.8 | 0.563 |
| SD | | 0.09 | 8.34 | 1.38 | 0.05 | 0.284 | 0.028 | 5.60 | 0.465 |
| Jackson | 61 | | | | | | | | |
| Range | | 0.03-0.46 | 2.33-23.60 | 0.37-8.54 | 0.28-0.70 | 0.006-0.059 | 0.004-0.711 | 0.0-24.0 | 0.000-8.343 |
| Mean | | 0.29 | 10.18 | 3.07 | 0.41 | 0.014 | 0.131 | 6.1 | 1.533 |
| SD | | 0.08 | 5.12 | 1.62 | 0.09 | 0.009 | 0.134 | 8.26 | 2.080 |
| Jefferson | 3 | | | | | | | | |
| Range | | 0.22-0.31 | 4.25-13.70 | 2.78-4.31 | 0.37-0.57 | 0.016-0.024 | 0.197-0.326 | 8.0-28.0 | 1.950-7.340 |
| Mean | | 0.27 | 9.15 | 3.47 | 0.49 | 0.020 | 0.262 | 17.0 | 4.579 |
| SD | | 0.05 | 4.73 | 0.77 | 0.11 | 0.004 | 0.065 | 10.15 | 2.700 |

TABLE F. Continued

| County | No. of Samples | Exchangeable K | Ca | Mg | Na | Fe | Mn | H | Al |
|---|---|---|---|---|---|---|---|---|---|
| | | meq/100 g | | | | | | | |
| Johnson | 4 | | | | | | | | |
| Range | | 0.16-0.24 | 1.58-4.25 | 1.95-7.29 | 0.33-0.78 | 0.008-0.016 | 0.067-0.677 | 1.0-21.0 | 0.556-6.785 |
| Mean | | 0.21 | 2.57 | 4.08 | 0.46 | 0.011 | 0.226 | 9.8 | 3.323 |
| SD | | 0.04 | 1.18 | 2.27 | 0.21 | 0.003 | 0.301 | 8.56 | 2.591 |
| Kankakee | 15 | | | | | | | | |
| Range | | 0.16-0.42 | 4.45-14.05 | 1.76-4.31 | 0.24-0.46 | 0.008-0.018 | 0.015-0.036 | 0.0-0.0 | 0.056-0.612 |
| Mean | | 0.30 | 10.38 | 2.70 | 0.35 | 0.014 | 0.022 | 0.0 | 0.367 |
| SD | | 0.07 | 2.71 | 0.70 | 0.07 | 0.004 | 0.006 | 0.00 | 0.148 |
| Knox | 236 | | | | | | | | |
| Range | | 0.20-2.08 | 4.45-22.40 | 2.32-16.21 | 0.22-0.74 | 0.002-0.047 | 0.007-0.546 | 0.0-7.0 | 0.000-1.390 |
| Mean | | 0.36 | 9.96 | 4.52 | 0.38 | 0.012 | 0.062 | 0.1 | 0.289 |
| SD | | 0.15 | 2.30 | 1.68 | 0.07 | 0.007 | 0.050 | 0.72 | 0.210 |
| LaSalle | 25 | | | | | | | | |
| Range | | 0.07-0.51 | 0.09-25.00 | 0.84-8.96 | 0.22-0.57 | 0.000-0.859 | 0.007-0.546 | 0.0-31.0 | 0.334-23.359 |
| Mean | | 0.23 | 9.09 | 4.02 | 0.40 | 0.070 | 0.156 | 15.3 | 6.440 |
| SD | | 0.13 | 6.64 | 2.08 | 0.10 | 0.165 | 0.149 | 11.11 | 7.006 |
| Marshall | 1 | 0.31 | 8.25 | 0.73 | 0.50 | 0.027 | 0.326 | 1.4 | 0.334 |
| McDonough | 1 | 0.27 | 9.50 | 3.74 | 0.43 | 0.018 | 0.028 | 0.0 | 0.056 |
| Menard | 1 | 0.27 | 13.70 | 3.61 | 0.48 | 0.052 | 0.073 | 0.0 | 0.167 |
| Mercer | 1 | 0.26 | 7.25 | 3.13 | 0.35 | 0.012 | 0.028 | 0.0 | 0.334 |

TABLE F. Continued

| County | No. of Samples | Exchangeable K | Ca | Mg | Na | Fe | Mn | H | Al |
|---|---|---|---|---|---|---|---|---|---|
| | | meq/100 g | | | | | | | |
| Peoria | 69 | | | | | | | | |
| Range | | 0.20-0.79 | 6.00-21.20 | 1.43-10.67 | 0.28-0.70 | 0.014-0.024 | 0.015-0.344 | 0.0-19.0 | 0.060-5.300 |
| Mean | | 0.35 | 12.43 | 6.18 | 0.47 | 0.020 | 0.084 | 1.0 | 0.430 |
| SD | | 0.09 | 3.78 | 2.02 | 0.09 | 0.003 | 0.066 | 3.29 | 0.720 |
| Perry | 214 | | | | | | | | |
| Range | | 0.14-0.73 | 3.15-23.90 | 0.63-8.13 | 0.22-1.24 | 0.003-0.021 | 0.004-0.881 | 0.0-20.0 | 0.000-6.229 |
| Mean | | 0.35 | 12.86 | 3.81 | 0.46 | 0.011 | 0.057 | 0.5 | 0.429 |
| SD | | 0.09 | 3.16 | 1.46 | 0.16 | 0.003 | 0.084 | 2.59 | 0.689 |
| Pope | 1 | 0.22 | 1.75 | 4.75 | 0.39 | 0.013 | 0.189 | 4.0 | 1.224 |
| Randolph | 68 | | | | | | | | |
| Range | | 0.04-0.81 | 7.00-21.20 | 0.52-7.50 | 0.24-1.30 | 0.003-1.611 | 0.007-0.160 | 0.0-24.0 | 0.111-1.613 |
| Mean | | 0.38 | 14.48 | 3.72 | 0.53 | 0.050 | 0.046 | 0.5 | 0.521 |
| SD | | 0.13 | 3.55 | 1.46 | 0.22 | 0.193 | 0.032 | 3.00 | 0.268 |
| Saline | 144 | | | | | | | | |
| Range | | 0.06-0.79 | 0.45-19.30 | 0.41-9.58 | 0.15-1.28 | 0.007-0.806 | 0.004-0.897 | 0.0-27.0 | 0.056-10.345 |
| Mean | | 0.29 | 6.41 | 2.99 | 0.39 | 0.021 | 0.126 | 5.4 | 1.577 |
| SD | | 0.10 | 4.06 | 1.86 | 0.15 | 0.066 | 0.164 | 6.90 | 2.010 |
| Schuyler | 36 | | | | | | | | |
| Range | | 0.16-0.50 | 2.33-20.60 | 1.43-7.71 | 0.35-0.74 | 0.008-0.029 | 0.004-0.127 | 0.0-14.0 | 0.167-3.838 |
| Mean | | 0.31 | 8.98 | 4.75 | 0.47 | 0.017 | 0.044 | 1.9 | 0.640 |
| SD | | 0.07 | 3.95 | 1.42 | 0.08 | 0.006 | 0.030 | 3.41 | 0.616 |
| Scott | 1 | 0.22 | 2.80 | 0.67 | 0.30 | 0.017 | 0.036 | 18.0 | 4.449 |

TABLE F. Continued

| County | No. of Samples | Exchangeable K | Ca | Mg | Na | Fe | Mn | H | Al |
|---|---|---|---|---|---|---|---|---|---|
| | | meq/100 g | | | | | | | |
| Stark | 22 | | | | | | | | |
| Range | | 0.20-0.54 | 6.25-16.15 | 2.50-6.88 | 0.30-0.43 | 0.018-0.021 | 0.015-0.175 | 0.0-0.0 | 0.056-0.556 |
| Mean | | 0.30 | 10.80 | 4.54 | 0.37 | 0.019 | 0.048 | 0.0 | 0.334 |
| SD | | 0.08 | 2.88 | 1.16 | 0.04 | 0.001 | 0.036 | 0.0 | 0.118 |
| St. Clair | 118 | | | | | | | | |
| Range | | 0.17-0.82 | 2.33-25.00 | 0.63-13.88 | 0.23-1.26 | 0.003-0.026 | 0.004-0.284 | 0.0-20.0 | 0.056-8.343 |
| Mean | | 0.40 | 12.72 | 4.37 | 0.52 | 0.011 | 0.044 | 0.5 | 0.491 |
| SD | | 0.12 | 3.69 | 2.05 | 0.18 | 0.005 | 0.043 | 2.31 | 0.818 |
| Vermilion | 64 | | | | | | | | |
| Range | | 0.13-0.53 | 1.58-25.00 | 1.38-14.33 | 0.16-0.93 | 0.003-0.056 | 0.007-0.677 | 0.0-17.0 | 0.111-5.228 |
| Mean | | 0.31 | 10.83 | 3.83 | 0.45 | 0.008 | 0.051 | 0.9 | 0.580 |
| SD | | 0.09 | 5.10 | 2.22 | 0.14 | 0.008 | 0.083 | 3.34 | 0.915 |
| Wabash | 1 | 0.11 | 2.68 | 2.23 | 0.41 | 0.023 | 0.114 | 11.4 | 3.949 |
| Will | 46 | | | | | | | | |
| Range | | 0.16-0.43 | 2.50-17.9 | 0.59-6.88 | 0.28-0.61 | 0.010-0.025 | 0.015-0.124 | 0.0-10.4 | 0.278-4.283 |
| Mean | | 0.28 | 7.94 | 3.10 | 0.39 | 0.014 | 0.041 | 0.3 | 0.688 |
| SD | | 0.07 | 3.61 | 1.23 | 0.07 | 0.004 | 0.021 | 1.60 | 0.562 |
| Williamson | 232 | | | | | | | | |
| Range | | 0.07-0.88 | 0.17-62.00 | 0.23-9.38 | 0.20-1.24 | 0.008-1.212 | 0.004-0.945 | 0.0-27.0 | 0.000-16.463 |
| Mean | | 0.32 | 8.68 | 3.26 | 0.40 | 0.035 | 0.127 | 6.2 | 1.903 |
| SD | | 0.12 | 6.68 | 1.85 | 0.12 | 0.078 | 0.166 | 7.97 | 2.989 |

TABLE F. Continued

| Region[a] | No. of Samples | Exchangeable K | Ca | Mg | Na | Fe | Mn | H | Al |
|---|---|---|---|---|---|---|---|---|---|
| | | meq/100 g | | | | | | | |
| Region I | 912 | | | | | | | | |
| Range | | 0.06-2.08 | 2.50-54.50 | 0.63-16.21 | 0.22-1.09 | 0.001-2.040 | 0.004-0.830 | 0.0-40 | 0.000-5.300 |
| Mean | | 0.34 | 10.84 | 4.51 | 0.41 | 0.030 | 0.050 | 0.4 | 0.380 |
| SD | | 0.13 | 3.96 | 1.68 | 0.08 | 0.080 | 0.060 | 2.41 | 0.430 |
| Region II | 92 | | | | | | | | |
| Range | | 0.03-0.78 | 0.09-41.25 | 0.59-8.96 | 0.22-0.61 | 0.010-1.400 | 0.004-0.817 | 0.0-31 | 0.060-23.360 |
| Mean | | 0.27 | 9.17 | 3.35 | 0.38 | 0.030 | 0.075 | 3.5 | 1.610 |
| SD | | 0.12 | 5.17 | 1.53 | 0.07 | 0.120 | 0.116 | 7.72 | 3.390 |
| Region III | 110 | | | | | | | | |
| Range | | 0.13-0.53 | 0.75-25.00 | 0.67-14.33 | 0.16-0.93 | 0.003-0.056 | 0.004-0.677 | 0.0-22 | 0.111-8.676 |
| Mean | | 0.30 | 9.74 | 4.07 | 0.45 | 0.012 | 0.050 | 1.9 | 0.787 |
| SD | | 0.08 | 4.93 | 2.02 | 0.12 | 0.009 | 0.069 | 4.72 | 1.329 |
| Region IV | 404 | | | | | | | | |
| Range | | 0.06-0.88 | 0.17-62.00 | 0.23-9.58 | 0.15-1.28 | 0.005-1.212 | 0.004-0.945 | 0.0-27 | 0.000-16.463 |
| Mean | | 0.30 | 7.67 | 3.22 | 0.40 | 0.028 | 0.124 | 5.7 | 1.726 |
| SD | | 0.11 | 5.81 | 1.86 | 0.13 | 0.072 | 0.163 | 7.48 | 2.605 |
| Region V | 466 | | | | | | | | |
| Range | | 0.03-0.82 | 2.33-25.00 | 0.37-13.88 | 0.22-1.30 | 0.003-1.611 | 0.004-0.881 | 0.0-28 | 0.000-8.343 |
| Mean | | 0.36 | 12.66 | 3.83 | 0.48 | 0.017 | 0.063 | 1.4 | 0.636 |
| SD | | 0.11 | 3.86 | 1.69 | 0.17 | 0.075 | 0.085 | 4.51 | 1.115 |
| Illinois | 2,084 | | | | | | | | |
| Range | | 0.03-0.88 | 0.09-62.00 | 0.23-16.21 | 0.15-1.30 | 0.001-2.040 | 0.004-0.945 | 0.0-40 | 0.000-23.360 |
| Mean | | 0.33 | 10.42 | 3.98 | 0.42 | 0.026 | 0.070 | 2.0 | 0.833 |
| SD | | 0.11 | 4.75 | 1.76 | 0.11 | 0.071 | 0.099 | 5.37 | 1.774 |

[a]See Fig. 3.

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5-94